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THE MAINTENANCE OF SOIL FERTILITY IN UGANDA

I. SOIL FERTILITY EXPERIMENT AT SERERE

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Summary

A comprehensive rotation experiment of phasic design has completed three cycles of a five-year rotation, making fifteen years in all. The main effects studied comprise crop–rest sequence, type of resting cover, and farmyard manure. Fertilizers are not included.

The trend shown by the sum of all crops in the rotation is used as an index of the trend of soil fertility.

In the absence of manure the land could not be cropped safely for more than three years in five. Given 5 tons of farmyard manure per acre every fifth year it was possible to crop four years in five, and the results suggest that with slightly more manure continuous cropping may be possible.

Yields of individual crops were greater after the longer rest periods. But these increases did not compensate for lack of crop while the land is resting.

Resting covers tested include a leguminous cover crop, ungrazed grass, and grass grazed during the day. No differential effects on soil fertility have been observed.

Response to farmyard manure is the dominant feature of the experiment, and residual effects can be traced through to the fifth year after application.

The bearing of these results on the local farming system is considered.

MAINTENANCE of soil fertility by the traditional African practice of shifting cultivation is no longer practicable in many parts of Uganda. Rising populations and the advent of cash crops have put too much pressure on the land. Early attempts by the Department of Agriculture to sustain continuous cultivation by the use of green manures led to severe erosion by run-off of rain-water and consequent loss of fertility. Attention then turned towards resting arable land under grass, and Martin and Biggs [1] designed the present experiment to elucidate the following questions, viz. what are:

1. the minimum period of rest necessary to maintain fertility;
2. the best type of cover during rest;
3. the effect of green manuring;
4. the dosage of animal manure necessary in conjunction with the above?

The experiment was laid down at Serere, which is situated in Teso

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district in lat. 1° 31′ N. and long. 33° 27′ E. at an altitude of 3,700 feet. Mean monthly maximum air temperatures vary between 81 and 92° F. and minimum temperatures between 62 and 65° F. The mean annual rainfall is 53 in., with peaks in April–May and August–September and a hot dry season in January–February. The soil is a light brown sandy loam subject to surface capping. The natural vegetation is Combretum scrub which includes Butyrospermum, Ficus, and Terminalia.

The agriculture of the Teso people in the Serere area has been described by Wilson and Watson [2] and on the lighter soils of the Ngora area by Wilson [3]. They practise a system of dual husbandry by which arable and range lands are farmed in parallel. Their staple food is finger millet (*Eleusine coracana* Gaertn.) and their main sources of income are cotton and livestock. Oxen are extensively used for ploughing.

The site of the experiment was acquired in 1934 as an extension to Serere farm and was allowed to rest under natural vegetation for two to six years. Before that some of it had been cultivated by the African population. The experiment is on level ground and all plots are separated by grass paths, so that the cultivated area is not subject to erosion by water. Trees have been removed and soil fertility is not affected by leaf fall from extraneous sources.

Soil physics on the site and elsewhere in Uganda has been discussed by Martin [4], Pereira, Chenery, and Mills [5], Pereira [6], and Pereira and Hosegood [7], and soil chemistry by Chenery [8]. The general progress of the experiment has been discussed by Kerkham [9] and in more detail by Kerkham and Williams [10].

Responses to small dressings of farmyard manure have been reported by Hartley and Greenwood [11] and Hartley [12] in northern Nigeria, and rotations with velvet bean as a green manure by Vine [13] in southern Nigeria. Experiments with kindred interest have been reported by Peat and Brown [14] in Tanganyika and by Anthony and Willimott [15] in the southern Sudan.

This paper reports the yields of crops harvested in the first fifteen years of the experiment.

Design of Experiment

The terminology proposed by Yates [16] is employed. The experiment follows a five-year rotation and is divided into five series of plots, which were opened in the years 1936 to 1940 inclusive, so that each phase of the rotation is represented each year. There are two absolute replications in each series, making ten replicates in all. All the series have completed three cycles of the rotation.

Each replicate contains fifteen major plots accommodating all combinations of three crop–rest sequences (R_1, R_2, R_3) and five types of resting cover (A, B, C, D, E). Each major plot is split into three subplots to accommodate three levels of farmyard manure (M_0, M_1, M_2). Fertilizers are not included, since their cost in Uganda when the experiment was designed held out no prospect of an economic return. It is a practical necessity that all rotations should be of the same length and

their division into crop–rest sequences proceeds according to the following plan:

		Crop–rest sequence		
Year	*Season*	4:1 (R_1)	3:2 (R_2)	2:3 (R_3)
1	a	PREPARATION OF LAND		
	b	cotton	cotton	cotton
2	a	finger millet	finger millet	finger millet
		MANURE APPLIED		
	b	cotton	cotton	cotton
3	a	groundnuts	groundnuts	REST
	b	sweet potatoes	sweet potatoes	
4	a	sorghum	REST	REST
	b	cotton		
5	a and b	REST	REST	REST

The five types of resting cover are:

A natural regeneration,
B grass undisturbed,
C green manure lopped,
D grass cut (1st cycle), then grazed (2nd and 3rd cycles),
E green manure dug in.

Farmyard manure, brought from elsewhere, is applied at rates of 0, 2½, and 5 tons per acre (M_0, M_1, M_2) once in the rotation.

Procedure in the Field

When cropped land is allowed to regenerate naturally the first species to appear in abundance is *Digitaria velutina* Beauv. This is followed by *Tridax procumbens* L., *Erigeron bonariensis* L., and a number of shrubby legumes, mainly *Crotalaria* spp. The secondary climax is *Imperata cylindrica* Beauv., which, although a troublesome weed to eradicate, is not regarded as such a pernicious weed in Uganda as it is in the Far East.

In the first and second cycles of the two grass treatments *Cynodon plectostachyum* Pilger was planted, but sown *Chloris gayana* Kunth. was substituted in the third cycle of the rotation. Grass was cut, supposedly to simulate grazing, in the first cycle of treatment D, but these plots were then fenced and grazed by cattle in the second and third cycles. The cattle grazed in the daytime only and were taken to a shed at night. They spent an hour at least walking to and from the shed and picked up some grazing on the way. But they were not normally given supplementary food at night. No rigid system was adopted to determine the length of the grazing cycles. Each major plot of three manurial sub-plots was fenced and grazed as one. When the farm manager decided that sufficient grass was available he arranged for all treatment-D plots in each block to be grazed in sequence. The time spent on each plot was decided by the amount of grass available and its ability to satisfy the animals' appetites.

Grazing made opening-up after the fallow easier than in treatments where much grass had to be turned in, although some cases of excessive compaction occurred where the cover had been poor. Grazing also prevented yellowing during the early stages of growth of the subsequent crop. This yellowing commonly occurs when a bulk of grass is dug in and insufficient time elapses before planting the crop, because the available nitrogen is consumed by the bacteria rotting the grass. To this extent grazing should have been beneficial. On the other hand a high proportion of the animals' food was taken from the plots and much of their dung and urine dropped in the shed at night, so that some transference of fertility away from the experiment must have occurred, as in the work reported by Sears [17] in New Zealand.

Velvet bean (*Mucuna deeringiana* (Bort) Holland) was sown in both green-manure treatments in March. In treatment C this was lightly lopped in August and dug-in the following March. In treatment E it was dug-in and resown in August and dug-in again the following March. If continuing for more than one year the same cycle of events was repeated in each case. The cover was often thin and tended to be invaded by the species characteristic of natural regeneration in its earlier stages.

Every endeavour has been made to adhere to standard field practices for all crops. Standard varieties of finger millet, groundnuts, and sorghum (with very minor exceptions) have been used throughout. Several varieties of sweet potatoes have been used and yields of this crop have shown more irregularity than any other except fourth-year cotton. An attempt to perpetuate a standard variety of cotton was not successful and yields of cotton may reflect progress made in plant breeding. Failure to achieve adequate control of Imperata undoubtedly affected yields of crops in the early years.

Crop residues left on the plots are reincorporated. Cotton stalks are burnt and the ash scattered, and the straw and haulms from other crops are dug in. Yields are weighed before threshing and homestead residues such as millet chaff and groundnut shells are not returned to the plots.

Plan of Interpretation

Martin and Biggs did not suggest how the data should be processed, except to indicate that soil fertility would be judged from the yields of index crops. The authors follow this approach by setting up the concept of a soil in balance, whose fertility remains unchanged when it yields crops at a certain constant rate. They assume that there is a steady net gain of plant foods from parent rock and atmosphere over losses by leaching and oxidation. During the cropping period the losses, in crops removed, exceed this gain. During the resting period this gain is conserved and accumulates. Balance is achieved when at the end of each rotation the losses and gains are equal. The problem is then to determine the critical rate of crop removal. It is assumed that too high a rate of crop removal would lead to loss of fertility and a drop in yield. Similarly, too low a rate would lead to accumulation of fertility and a rise in yield. The present experiment is well fitted to do this and the treatments have been well chosen to straddle the critical rate which has to be determined.

For this procedure, however, there is no choice of index; the sum of all crops in the rotation must be used.

The next step is to determine the extent to which this critical rate of crop removal can be raised by the addition of farmyard manure brought from elsewhere.

It should then be possible to answer the first and fourth questions put by Martin and Biggs (see p. 179), and to say how the greatest weight of produce can be wrung from the land for the subsistence of an overcrowded population, but it is clear that this answer, for all its theoretical interest, may not appeal to reason in terms of profitable good husbandry. Martin and Biggs may have hoped that increase in crop size after a rest period would compensate for lack of crop during that rest, in which case no conflict would arise. But that hope is not fulfilled and it is necessary to add some comment on this separate and distinct issue, if only to avoid leaving false impressions.

The second and third questions put by Martin and Biggs ask, in effect, whether the critical rate of crop removal can be influenced by qualitative treatments, since there is no prima-facie reason why grasses and green manures, taking the long view, should add anything to the system (that is, if nitrogen fixation by root-nodule bacteria in the tropics is discounted).

Processing of Data

The experiment comprises 450 plots and 6,750 plot yields have accrued in the period under review. This is an ambitious programme for a remote station in Africa and the processing of the data has been a formidable task. It is worth noting that almost as much information could have been gained from little more than half the area by omitting treatments C and M_1.

The method used by Stevens [18] for successive yields of a perennial crop and discussed more generally by Pearce [19] has been adopted. The primary data have been processed to give the cumulative yields of all three cycles ($c_1+c_2+c_3$), the linear regression of yield on time (c_3-c_1) and the quadratic regression on time ($c_1-2c_2+c_3$). The linear regression provides the essential test of fertility trend. Only minor use has been made of the other two functions, but they have been of great value for checking the arithmetic.

This process can be applied to any one crop in the rotation, or to any combination of crops. For the reasons already given the authors have made the most use of the total harvest from all crops, which are referred to as 'rotation yield'. This represents all sun-dried produce removed from the land and is the sum of the following components:

cotton: lint and seed unginned (three crops),
finger millet: dried heads,
groundnuts: dried in the shell,
sweet potatoes: fresh weight $\times 0{\cdot}3$,
sorghum: dried heads.

No allowance has been made for the live-weight gains of cattle grazing on

treatment D in the second and third cycles. This omission is unlikely to have made any appreciable difference to the figures, as the yield of beef per acre per annum expressed as dry matter is known to be very small numerically. The fact that its cash value per unit of labour expended may be important is not relevant to the main inquiry. The disparity in the value and amounts of the different crops is also not relevant. But some inaccuracy is involved by ignoring qualitative differences between crops.

The contributions to rotation yield are shown in Table 1.

TABLE 1. *Contribution of Separate Crops to total Rotation Yield (lb./acre)*

	c_1	c_2	c_3	*Coefficient of variance % (all cycles)*
Cotton, first year .	428	567	693	12·1
Finger millet . .	1,311	1,625	1,595	13·8
Cotton, second year .	482	331	491	13·9
Groundnuts . .	1,434	1,398	1,278	12·7
Sweet potatoes . .	1,090	1,026	1,050	16·0
Sorghum . . .	1,737	2,189	1,265	11·1
Cotton, fourth year .	274	244	432	19·3
Rotation yield . .	4,574	4,949	4,897	9·5

Note. All crops are not equally represented in the three crop–rest sequences and the yields per acre shown in this table are only additive by taking two-thirds of the groundnuts and sweet potatoes and one-third of the sorghum and fourth-year cotton.

It will be seen that rotation yield has a much lower coefficient of variance than any of the crops. This is because it averages the varying behaviour of the different crops in response to treatments, and also because it allows for any compensation which may occur between yields of successive crops on the same plot. On the other hand, its trend in time suffers from certain errors. For example, the low figure of 428 for first-year cotton in the first cycle almost certainly reflects failure to control Imperata adequately. These errors must be accepted.

Missing values. In an experiment of this size and duration some misfortunes are inevitable and ideally the design should include a scheme for dealing with them. In the total of 6,750 possible plot yields 160 values are missing. Of these 10 were lost at different times from a variety of causes and calculated values have been supplied by conventional methods. In addition the finger millet in series II, cycle 1 (90 plots), was lost to locusts and the sweet potatoes in series I, cycle 1 (60 plots), were seriously upset by theft. Yields of these crops have been analysed individually by omitting the incomplete series in each case. Similarly a trial analysis of rotation yield has been made by omitting both incomplete series. But by doing this only three-fifths of the experiment is brought into view and much of the advantage of the phasic design is lost. It is also easy to see that a few more mishaps would reduce the available information to vanishing point.

To overcome this difficulty calculated values have been supplied for the missing finger millet crop by reference to the other fourteen crops in a table of the five series and three cycles, and then differentiating between the two replicates by reference to the block totals in the subsequent cycles of the same series. The missing crop was taken for preliminary yields and would not have been affected by treatments. Similarly, calculated values have been supplied for the missing sweet potato crop. But this was grown after manurial treatments had been applied and further adjustment has had to be made by reference to manurial treatment totals in the first cycle of the other four series.

The number of crop yields combined in the linear regression function is 6, 10, or 14, so that the arbitrary element is small if one of these is calculated. Each cycle gives 2,250 plot yields and to correct for this loss of information standard errors relating to c_3-c_1 have been raised by the factor:

$$\sqrt{\frac{4,500}{4,500-160}} = 1{\cdot}018.$$

There is no gain in precision from this process. The coefficient of variance for rotation yield omitting series I and II is 9·2 per cent., whereas by supplying the missing values and including all series it is 9·5 per cent. The latter course (which gives the same answer) is preferred for two reasons. It will be seen later that there are big differences in the pattern of yield between series, due to vagaries of season and management, which make it desirable to rest the experimental conclusions on the broadest basis possible. Moreover, if another mishap occurs, it may be possible to overcome it without having to reconstruct all the previous arithmetic.

Experimental Results

Each sub-plot measures 39×39 ft. and 1 acre is the equivalent of 28·6 plots. But the grass paths have some edge effect and the whole cultivated area is not fully utilized. To allow for this and economize in the arithmetic it is a convenience to regard each sub-plot as $\frac{1}{30}$th acre and the whole experiment as 15 acres. On this basis the general mean of the experiment is a rotation yield of 4,807 lb./acre.

There are no important interactions between main effects and advantage has been taken of this fact to simplify the presentation of the results as much as possible.

Crop–rest sequence. Table 2 supplies the information required to determine the critical rates of crop removal. The essential test of safe cropping is a positive entry in the last column of this table. It is clear that in the absence of farmyard manure (M_0) it has proved safe over a period of fifteen years to take crops from the soil of this experiment at the rate of some 2 tons every five years. With the rotation used, this has been achieved by cropping for three years out of five and resting for two (R_2M_0). Cropping for four years and taking away some 3 tons of produce has caused yields to decline (R_1M_0). If the experiment had been in tsetse country and farmyard manure had not been available, this result would have had a direct bearing on the local farming

TABLE 2. *Effect of Crop–rest Sequence on Rotation Yields in lb./acre*

(*all types of rest*)

		c_1	c_2	c_3	c_3-c_1
R_1	M_0	6,507	6,827	5,986	−521
	M_1	6,871	7,266	6,555	−316
	M_2	6,959	7,756	7,086	127
R_2	M_0	4,438	4,357	4,725	287
	M_1	4,755	5,032	5,301	546
	M_2	4,821	5,194	5,508	687
R_3	M_0	2,233	2,612	2,807	574
	M_1	2,299	2,728	2,972	673
	M_2	2,283	2,772	3,139	856
Least significant difference ($P = 0{\cdot}05$)					252

system. The pity is that in these circumstances there would also be no animals to take advantage of the rest period.

When farmyard manure is available at the rate of 5 tons per acre every fifth year (M_2) it may be possible to crop for four years and rest for one (R_1M_2), taking away rather more than 3 tons of produce. Owing to the big rise in yield in cycle 2 and subsequent drop in cycle 3, this point will be better determined when the yields from cycle 4 are available.

This result was not expected when the experiment was designed, and it now seems a pity that continuous cropping was not included as one of the treatments. It appears quite possible that an R_0M_3 treatment, that is continuous cropping with a rather heavier dressing of farmyard manure, would give a positive regression coefficient. In this connexion it is worth noting that the one-year rest, with green manure dug-in twice in the year (R_1E), approximates closely to continuous cropping from the point of view of soil disturbance; and it will be seen from Table 3 that R_1EM_2 differs hardly at all from the more general case.

TABLE 3. *Effect of Green Manure Dug-in on Rotation Yields in lb./acre*

	c_1	c_2	c_3	c_3-c_1
R_1 M_2	6,959	7,756	7,086	127
R_1 E M_2	6,870	7,830	7,000	130

But more manure would probably be necessary if crops were taken off the ground in the fifth year.

Table 2 shows clearly that any increases in the yields of individual crops after the longer rest periods did not compensate for lack of crop while the land was resting. Should uniform rates of change continue it will be another twenty years (thirty-five years in all) before any R_2 treatment can be expected to overtake a comparable R_1 treatment, and the R_3 group is completely out of the running.

Nevertheless, lengthening the rest period did increase the yields of individual crops quite substantially. This is seen in Table 4, which gives the combined yields in the third cycle of the three crops common to all three crop–rest sequences.

TABLE 4. *Combined Yield of Cotton–Finger Millet–Cotton in lb./acre*

(third cycle, all types of rest)

	R_1	R_2	R_3
M_0	2,359	2,621	2,807
M_1	2,584	2,899	2,972
M_2	2,668	2,966	3,139

The yields after the longer rest periods rose by almost 20 per cent. and this must be important in circumstances where land is not scarce, profit is the motive rather than quantity, and good use can be made of the resting fields by grazing animals on them.

A remarkable feature of Table 4 is the complete absence of any interaction between crop–rest sequence and manurial treatment. The fact that the longer resting sequences do not show an appreciably larger response to farmyard manure is of great theoretical interest. It will be seen later that all crops throughout the rotation have responded to manure and attempts made from time to time to estimate cover during rest indicated that resting covers also responded. If resting covers are beneficial, an improved cover should confer a larger benefit on the soil, and on the crops which follow. But there is no evidence of this happening, and the same negative result is obtained by examining the data for all five resting covers individually. From this the tentative conclusion is drawn that the resting covers tested had no positive effect of their own, although in other circumstances they might serve such purposes as the prevention of erosion or the control of eelworm. Thus the higher yields obtained after the longer rest periods in Table 4 may represent nothing more than accumulations of fertility consequent upon the shorter cropping periods, and there is no reason on this evidence to suppose that similar results would not have been obtained after a bare fallow. All the evidence of the subsequent section is concordant with this view.

Type of rest. Table 5 summarizes the evidence on these treatments.

TABLE 5. *Rotation Yields in lb./acre for all Crop–Rest Sequences and all Levels of Manure*

		c_1	c_2	c_3	c_3-c_1
A	Natural regeneration .	4,522	5,119	5,033	511
B	Grass undisturbed .	4,738	4,863	4,921	183
C	Green manure lopped	4,589	4,822	4,825	236
D	Grass cut, later grazed	4,604	5,098	5,011	407
E	Green manure dug-in	4,417	4,844	4,698	281

No differences significant.

The yields in the first cycle are true preliminary yields, as the resting treatments had not been applied. The range between sets in this cycle is 7 per cent. and this figure is not exceeded after application of the treatments. This bias in the sets has caused much confusion in the past. Over all the linear regression is not significant. Seemingly significant effects can be demonstrated by prejudged partition of the variance, both for type of rest and for its interaction with crop–rest sequence, but in each case the effect can be clearly related to bias in the original sets. A similar result is obtained by considering the yields of cotton–finger millet–cotton only, and the differences between treatments in the linear regression are then even smaller. Since no differential effects have been demonstrated, the simple contrast drawn by Kerkham and Williams [10] between grass treatments and green-manure treatments cannot be sustained. This negative evidence supports the previous tentative conclusion that these resting covers do not generate any positive effect of their own.

This conclusion must be restricted to cover treatments used in this experiment in circumstances not conducive to erosion. It does not apply to bush fallows or to elephant grass, both of which are believed to have an effect. It may not apply to long-term grass leys, remembering that old turf in temperate latitudes has valuable characteristics which are not exhibited by short-term leys.

Comparing treatments B and D in Table 5 across the interval between cycles 2 and 3 it does not appear that grazing has done any good or any harm. This evidence is still very inadequate, but at this stage there is no support for the preliminary conclusion drawn by Kerkham [9] in favour of grazing. It is possible that grazing conferred a temporary benefit by helping to control Imperata, but in the long run the system of management adopted must result in a transfer of fertility away from the experiment.

Farmyard manure. This has already been considered as a main effect in conjunction with crop–rest sequence, but the responses of individual crops are also interesting. These are set out in Table 6, with the first two crops of the first cycle (no treatment) omitted and the first two crops of the fourth cycle included to make the comparison orthogonal. It should be remembered that the manure is brought from elsewhere and applied every fifth year at rates of 0, $2\frac{1}{2}$, and 5 tons per acre (M_0, M_1, M_2). The effect of manure was lasting, as cotton and finger millet have given appreciable (and significant) responses 4 and $4\frac{1}{2}$ years after application. The fact that the mean yield of M_2 (117 per cent.) is much greater than that of M_1 (110 per cent.) indicates that a higher rate of application would be worth while if sufficient manure were available. There is also a significant difference (P less than 0·001) in the response pattern in time, ranging from cotton where it is cumulative with repeated application, to groundnuts and sweet potatoes where it is more immediate.

The authors have not attempted to investigate the response curves for farmyard manure with greater precision at this stage. They will be more easily determined when yields from the fourth cycle are available later in 1959.

TABLE 6. *Effect of Farmyard Manure. Yields of M_1 and M_2 as percentage of M_0*

(all crop–rest sequences and all types of rest)

	C_1		C_2		C_3	
	M_1	M_2	M_1	M_2	M_1	M_2
(manure applied)						
Cotton	107	109	122	131	130	148
Groundnuts	107	113	113	120	112	119
Sweet potatoes	115	110	119	134	108	123
Sorghum	104	109	106	110	111	118
Cotton	102	106	110	128	119	134
(rest)						
	C_2		C_3		C_4	
Cotton	102	100	103	104	108	114
Finger millet	105	106	106	107	109	115
Means	106	108	111	119	114	124
Cycle means	107		115		119	

Least significant difference between cycle means ($P = 0{\cdot}05$): 2·7

Environmental Effects

Hazards which led to actual loss of plot yields have already been mentioned when describing the procedure adopted for dealing with missing values. But there are other effects which should be mentioned to illustrate the kind of precautions which are necessary when conducting an experiment of this kind. The formal treatments have not given responses greater than 50 per cent. This general picture is put into perspective by the large difference between series shown in Table 7.

TABLE 7. *Rotation Yields in lb./acre for all Treatments*

	c_1	c_2	c_3	$c_1+c_2+c_3$	c_3-c_1
Series I	2,837	4,684	4,115	11,635	1,278
II	4,290	5,342	4,914	14,546	624
III	4,844	4,760	4,893	14,496	49
IV	6,027	4,682	4,013	14,722	−2,014
V	4,871	5,280	6,553	16,704	1,682
Mean	4,574	4,949	4,897	14,421	323

Management. The low figure for series I, cycle 1, is almost certainly due to failure to control Imperata effectively in the early years of the experiment. The major contrast between series IV and V can be related to the run of chance in the sowing date of crops as determined by season. These vagaries emphasize the need to be as consistent in points of management as circumstances will allow. They also supply a strong reason (mentioned when discussing missing values) for retaining all five series in the analysis to average the conclusions about treatments.

Ant-hills. It has been observed that cotton grows well on old ant-hills. There are 200 of these in the experiment and their position was recorded

at the end of the third cycle (1954). It can be shown by covariance (P less than 0·01) that first-year cotton yielded 7 per cent. more on plots containing an ant-hill. The nature of this relationship is being investigated by other workers. The other crops were less responsive and no over-all relation has been found between rotation yield and presence of ant-hills.

Discussion

The authors have not attempted to treat the results of this experiment exhaustively. There is scope for more elaborate statistical treatment, more especially when the yields from the fourth cycle of cropping are available. There are also many observations on the physical and chemical properties of the soil which will be reported by others. Much of this work is in hand. The present purpose is to set the background (since both the authors have followed the course of the experiment throughout the period under review) and to make certain suggestions for rounding off the investigation.

It must be emphasized that small plots free from erosion by water are more favoured than large fields on sloping land. Undoubtedly this is where the early attempts of the Department of Agriculture to crop continuously went wrong. But contour-strip cropping has now been widely adopted in the part of Uganda under discussion, and the conditions of the Serere experiment are no longer unrealistic.

The conclusions on the questions of rest period and manure are summed up below.

	No rest period	*Rest period*
No farmyard manure	not permissible	subsistence in tsetse country
Farmyard manure	subsistence in crowded areas	mixed farming for profit

Subsistence in crowded areas. Continuous cultivation using farmyard manure is not a self-contained system. In a highly developed farming system the land benefits directly from the use of fertilizers, and indirectly from the feeding of concentrates to livestock. In Uganda it is necessary to consider a closed system. But until such time as the majority of farmers can afford to use fertilizers and concentrates, the opportunity exists to build up fertility on arable land by transporting it from swamps in the form of animal manure. Nutrients accumulate in the swamps and this is not a spendthrift policy. The present system of dual husbandry is well adapted for this purpose. The problem is to ensure that enough manure reaches the arable land.

To do this in the form of farmyard manure requires housing for cattle at night and transport to the fields. An attractive alternative, if fencing can be arranged, is to range the animals in the swamps by day and paddock them by night on the arable land. This might be done in out-of-season breaks, or it might be necessary to include a short rest period in

the rotation for the purpose. But it is necessary to know whether this system will secure the same result without undue damage to the soil by compaction, and this test is being made in a separate experiment at Serere. It would be worth repeating the observations on compaction in an area of light land, notably on the sands in the eastern part of Teso district.

It is also necessary to test the suggestion that continuous cropping may be possible, with or without a heavier dressing of farmyard manure. No useful purpose will be served by continuing all five of the resting cover treatments in the present experiment, and it was noted that an opportunity presented itself in the third year of the fifth cycle (1958) to start converting some of these to continuous cropping. In this way the contrasts between the three existing crop–rest sequences would remain, and an orthogonal contrast would be set up to measure the rate of run-down (if any occurs) after conversion to continuous cropping. Arrangements could also be made for an extra, or heavier, dressing of farmyard manure. The experiment, which is a tremendous drain on experimental resources, could be discontinued when this question has been answered.

The effect of small dressings of farmyard manure accords well with the findings of Hartley and Greenwood [11] in northern Nigeria. The manner in which it operates has not yet been conclusively demonstrated at Serere and the results of work in progress will be awaited with interest. They may indicate the extent to which farmyard manure can be replaced or supplemented by chemical fertilizers.

Subsistence in tsetse country. It may be that chemical fertilizers can take the place of farmyard manure to some extent. In the meantime a rest period is necessary, and this raises the question of the type of resting cover that should be employed, as it would not be required for grazing. If fertility is promoted by the mobilization of nutrients from depth, a bush fallow should be more efficient than any shallow-rooted cover. In other parts of Uganda elephant grass (*Pennisetum purpureum* K. Schum.) serves this purpose. The system of burning brushwood in other parts of Africa and the use of *Acioa barteri* Engl. in eastern Nigeria are probably examples of the same principle. This aspect of the subject requires further study in Uganda.

Mixed farming for profit. The system of alternate husbandry, by which crops and stock are raised on the same land by rotating crops with ley grazing, is feasible where pressure on the land is not too great. In course of time social changes may make it possible in more densely populated areas. The majority would have to find other employment, leaving the land to be farmed by the few in units of adequate size. Expatriates from western Europe strive instinctively towards this system because it is familiar to them at home. The present purpose is to sift the evidence which can be advanced in favour of it.

The essential feature of this or of any other system of farming, as opposed to cultivation for subsistence, is that the crops individually shall bring a profit to the farmer in return for his outlay in money and toil. The present experiment was not designed to investigate this point and therefore cannot answer questions on profit.

It does, however, establish the essential fact that larger individual crops are obtained when the crops are fewer in number and a rest period is inserted in the rotation. But it adds a corrective by pointing consistently to the conclusion that manuring and cropping are straightforward exercises in addition and subtraction, leaving no room for any 'magical' effects from grass and grazing other than the well-known conveniences of the system.

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CAPSIDS AS A FACTOR INFLUENCING THE EFFECT OF SWOLLEN-SHOOT DISEASE ON CACAO IN NIGERIA

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Summary

The unrestricted spread of cacao swollen-shoot disease was followed by monthly observations on naturally occurring outbreaks in the Abeokuta and Ibadan Provinces of Western Nigeria. The condition of the trees was more closely related to the incidence of capsid damage and associated dieback caused by *Calonectria rigidiuscula* (Berk. & Br.) Sacc. than it was to swollen-shoot virus infection. Indeed, where capsid damage was slight or where it was controlled by spraying, the effect of virus was less marked than that due to other factors influencing growth and yield. By comparison, where capsid damage was severe and not controlled, virus infected trees were worse than their neighbours and often died within a few years. These results suggest a new approach to cacao swollen shoot disease and its control, in which the interactions of pests and diseases in their environment are treated as a single ecological problem.

In Ghana the most virulent strains of cacao swollen-shoot virus drastically affect the growth and yield of cacao trees and there are many records of death within a few years [1, 2, 3]. The situation in Nigeria is similar but the differences between healthy and infected trees are not so great and infected trees do not always die.

In both Ghana and Nigeria the deterioration of diseased trees has usually been attributed solely to the effects of virus, but most observations were made before capsids could be adequately controlled. These insects and the fungi associated with their feeding punctures are so widespread in cacao that they must have already damaged most trees before virus infection occurred. Furthermore, Williams [4] showed that capsids and associated fungi and possibly thrips could build up and seriously damage trees already weakened by virus. Experience also shows that infected trees survive longer under favourable conditions than elsewhere. These observations suggest that the effects of virus infection in cacao are considerably influenced by other diseases and pests and also by the environment.

This thesis can now be tested in the field, since chemicals and apparatus for insect control have recently become available; the results of preliminary experiments are presented here. Typical strains of the cacao swollen-shoot viruses in Nigeria had lethal effects only when the infected trees were also attacked by capsids and fungi and particularly where they were growing under unfavourable conditions. Indeed, where capsids were not numerous or where they were controlled by routine sprays, virus infection became just another debilitating factor, of less importance than others influencing growth and yield. These results suggest a new approach to cacao swollen-shoot disease and its control in

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West Africa, in which the interaction of pests and diseases and the environment is treated as an ecological problem.

Methods

Until recently it has been impossible to obtain uniform plots of healthy trees for inoculation in formal experimental designs. Consequently, work has been restricted to observations on naturally occurring outbreaks in irregularly spaced Amelonado cacao in the Ibadan and Abeokuta Provinces of Western Nigeria.

All the outbreaks were found during routine survey operations. At each plot the trees were numbered and inspected monthly, when the presence or absence of leaf symptoms and swellings was noted by the same observer. The plots had been neglected by their owners, so that routine maintenance operations had to be carried out. Trees on certain plots were also harvested regularly and sprayed with copper fungicide and gamma B.H.C. These were applied as mists by knapsack machines, and black pod disease and the major insect pests, including capsids and thrips, were virtually eliminated.

Outbreaks were observed at Iweke, near Ilaro, in Abeokuta Province and at the following villages in Ibadan Province:

Offa-Igbo:	30 miles north-east of Ibadan, off the Iwo road.
Koroboto:	16 miles east of Ibadan, off the Ife road.
Ajia:	18 miles ,, ,, ,,
Oluwa:	14 miles ,, ,, ,,
Ajule:	15 miles ,, ,, ,,
Abuku:	18 miles south of Ibadan, off the Shagamu road.
Araromi:	18 miles ,, ,,

The Effect of Virus on Growth and Yield

Observation Plots where Capsids were not Controlled

Offa-Igbo. Capsid damage and associated dieback caused by *Calonectria rigidiucula* (Berk. & Br.) Sacc. [5, 6] were already obvious on many trees when observations commenced in 1953. Most of the virus-infected trees were more severely affected than their neighbours, but all the trees were in poor condition and had begun to decline before they became infected with virus. The canopy of fan branches was almost completely destroyed by 1956, when virus infection was almost complete and an extensive ground vegetation of grasses and herbaceous weeds had invaded the plot. This was then abandoned and in September 1958, 258 of the 296 trees were dead or moribund.

Abuku. Most of the twenty-six infected trees in this small outbreak were moribund in 1958 and no longer bore pods. However, adjacent trees were in a similar condition and the whole farm had been so severely attacked by capsids and dieback that it had been abandoned and an extensive ground vegetation allowed to develop. Elsewhere in the area, unsprayed cacao without virus was in similarly bad condition and of the few trees which were bearing pods in the 1958 main-crop season most

were in a plot at Omi Aboderin, where trees infected with cacao necrosis virus were sprayed against capsids.

Koroboto I. This plot and the one immediately alongside (Koroboto II) were in a similar condition in 1956, when most of the trees were attacked by capsids and showed dieback. Many trees were dead or moribund by 1958 and most of the survivors were infected with virus. The canopy of the trees in the open was virtually destroyed and the remaining leaves were chlorotic. Dieback was severe and an extensive ground vegetation had developed. By comparison, infected trees in the shade of kolas and oil palm still retained some of their sparse canopy branches and continued to yield. They had been infected with virulent virus strains for some years and the shade trees had apparently ameliorated the effects of virus.

Iweke. The trees at Iweke were well maintained and vigorous when virus was found there in 1953. By October 1958, 141 of the 1,490 trees had been found with symptoms, but the farm remained in good condition and similar to adjacent ones without virus symptoms. Some trees were chlorotic or showed obvious symptoms of iron deficiency. Furthermore, thrips were numerous on the leaves and pods and apparently caused some defoliation, but capsids were rare and few trees showed signs of recent damage or dieback. Under these conditions there was no obvious difference between the virus-infected trees and their neighbours. Indeed, some trees had shown virus symptoms for several years and continued to yield satisfactorily. For example, one tree which was first found with symptoms in March 1956 produced 137 pods in the 1956–7 crop season and 97 pods the following year, when yields were generally low. The infected trees produced an average of 24·8 pods per tree in the 1956–7 season and 19·5 in 1957–8. By comparison, the symptomless trees produced 21·9 and 11·7 pods per tree in the same periods. The superior performance of the infected trees in both seasons suggests that in the absence of severe capsid damage the effect of virus at Iweke is less than that due to other factors affecting growth.

Observation Plots where Capsids were Controlled

Koroboto II (sprayed since February 1956). The spread of virus has been followed on this plot since 1953, and in January 1956 most of the virus-infected trees were worse than their neighbours. Nevertheless, capsid damage and dieback were obvious on most trees and some had chlorotic leaves, particularly where the canopy had been broken and had allowed ground vegetation to develop. All the trees were subsequently sprayed monthly with gamma B.H.C. at the rate of 4 oz. per acre. Capsid damage has since been completely checked and the few trees that died included some with virus symptoms and others without (Table 1). Similar effects have been noted elsewhere in Nigeria after spraying farms where the cacao was severely damaged but virus-free. The recovery of the surviving trees was striking and most of the dead twigs and branches were lost as the trees made vigorous new growth from their remaining relatively undamaged parts.

TABLE 1. *Yields at the Koroboto II Observation Plot*

Trees first showed symptoms in:	*Mean Number of Pods per Living Tree**				
	1954–5	*1955–6*	*1956–7*	*1957–8*	*1958–9*
1953 . .	**8·8** (49)	**6·8** (46)	**11·7** (45)	**17·7** (44)	**29·4** (43)
1953–4 .	**11·1** (52)	**11·4** (51)	**22·0** (50)	**20·7** (50)	**35·2** (49)
1954–5 .	**16·6** (69)	**11·4** (69)	**14·2** (68)	**15·6** (68)	**24·9** (68)
1955–6 .	20·0 (119)	**21·1** (119)	**20·4** (118)	**19·8** (117)	**28·1** (116)
1956–7 .	21·8 (113)	17·7 (113)	**27·5** (113)	**19·4** (112)	**21·0** (112)
1957–8 .	17·3 (137)	12·7 (137)	18·6 (137)	**17·2** (137)	**20·9** (135)
Symptomless	11·2 (285)	10·2 (281)	14·3 (275)	11·2 (272)	19·0 (271)
All trees .	15·2 (824)	13·2 (816)	18·1 (806)	16·0 (800)	23·9 (794)

* Yields in heavy type were from trees which were showing symptoms. Twenty pods per tree, on this plot, is equivalent to approximately 720 pounds of dry cocoa per acre. The number of living trees in each category and crop season is given in parentheses.

Yield records have been taken monthly at Koroboto since August 1954 and a preliminary analysis showed that infection had not reduced the bean content of the pods or their weight. Data for the mean number of pods per tree are summarized in Table 1, in which the trees are grouped according to the year in which they were first found with symptoms. Thus, comparisons between the rows of the table are invalid as positional effects are confounded with those caused by virus. Further, there are no valid controls and some of the symptomless trees are latently infected. Others have probably escaped infection, in some instances because of their small size and limited contact with other trees. Nevertheless, the data for each group of trees in successive years indicate yield trends, and spraying against capsids has been associated with a large increase in the yield of the oldest surviving infections. By comparison, the yields of the relatively undamaged trees which were infected recently or not at all have remained relatively stable and merely indicate seasonal fluctuations. Spraying has maintained and even increased yields and checked any further deterioration in condition, even though some trees have been infected for five years and the number of infected trees increased during the spraying period from 24·4 per cent. of the total to 63·7 per cent. in July 1958.

The virus strains occurring at Koroboto vary in virulence and in the symptoms they cause. Typical ones resemble those occurring at other localities in Nigeria. Consequently the results obtained at Koroboto are probably relevant elsewhere in Nigeria, and this has already been substantiated.

Ajia I (sprayed since February 1956) and *Ajia II* (sprayed since November 1957). The virus at these adjacent plots has apparently had mild effects and trees with virus symptoms and others without were in reasonable condition when observations started on Ajia I in 1956 and on Ajia II in 1957. Capsids and dieback were rare in both plots, which were in far better condition than nearby farms without virus. Regular spraying started after the initial observations, and the trees have continued to grow and yield satisfactorily, with no evidence of any deteriora-

tion due to the unrestricted spread of virus. Indeed, each of the trees infected by 1957 produced an average of 25·7 pods in the 1956–7 crop season and 30·1 in 1957–8. By comparison, the symptomless trees produced 15·9 and 21·0 pods in the same period; a further indication that the effect of virus on yield is not so important as other factors. The differences between the yields of the trees within quite small areas here and at Koroboto are not unique and similar ones have been noted elsewhere in West Africa [7] and in clonal cacao in the West Indies [8]. They are likely to become increasingly apparent as capsids and virus are controlled and environmental factors become more obvious and important than hitherto.

Ajule (sprayed since November 1957). The farm was unsatisfactory when observations started in 1957, and capsid damage, dieback, and chlorosis were common on most of the trees, which did not form a closed canopy. However, the condition of the trees was not obviously related to the distribution of virus and some of the most severely damaged ones were remote from the nearest infection symptoms. Spraying has now checked any further deterioration and the trees are recovering, although it will be some time before the trees form a closed canopy and are fully restored.

Oluwa (sprayed since August 1958). When observations started at this farm in 1958 there was an apparent association between the condition of the trees and the incidence of virus. This was shown quantitatively using the canopy scoring system previously described [9]. Vigorous trees with a complete canopy were placed in category one, and moribund trees living only at the base, in category five. Most of the trees were in intermediate groups with obvious dieback; trees with virus symptoms were given a mean score of 3·6 compared with 2·4 for the others. However, some infected trees were in good condition and certain symptomless ones were not (Table 2). This suggests that the condition of the trees was not solely due to the presence of virus, which by chance may have largely coincided with an area of severe capsid damage or of unfavourable conditions. Alternatively, virus may have weakened the trees and caused a break in the canopy which allowed capsids to multiply and cause extensive damage [4]. The trees were sprayed first in August 1958 and virtually all trees made extensive new growth at the subsequent flushing period in October. Trees with virus symptoms, and others without, behaved similarly, and it appears that their decline has been arrested and that the farm will be greatly improved if capsid control is maintained by additional sprays applied whenever necessary.

Araromi (sprayed in August and September 1956). The monthly sprays at Koroboto, Ajia, and Ajule were intended to eliminate all complicating effects caused by insects. They were unnecessarily frequent for the control of capsids, and virus-infected trees at Araromi recovered after less drastic and expensive treatments. The 5-acre plot was sprayed with 4 oz. of gamma B.H.C. per acre in August and September 1956, as part of a large-scale capsid-control experiment [10]. Spot treatments were applied subsequently on the few occasions when additional capsids or capsid damage were found. These continued until January 1957 and

recovery was followed quantitatively by monthly observation on the condition of 100 marked trees.

TABLE 2. *The Canopy Condition of Trees in an Outbreak of Swollen-shoot Disease at Oluwa*

Category	Canopy Category in July 1958					Total
	1	2	3	4	5	
No. of trees with virus symptoms in July 1958	0	8	25	19	7	59
No. of trees without virus symptoms	83	101	90	53	8	335
Total*	83 (0·0)	109 (7·9)	115 (21·7)	72 (26·4)	15 (46·6)	394 (15·0)

Categories defined by Lister and Thresh [9]; ranging from 1—virtually undamaged, to 5—moribund.

* The percentage number of virus infected trees in each canopy category is given in parentheses.

In November 1958 swollen-shoot disease was found in the plot, and infection was so extensive that some trees must have been infected from the outset of the experiment. Nevertheless, the behaviour of the forty-eight marked trees which were found with symptoms in 1958 had been similar to that of the symptomless ones (Table 3). Both groups of

TABLE 3. *Canopy Condition of Trees in an Outbreak of Swollen-shoot Disease at Araromi, which was sprayed in August and September 1956**

Category	Mean canopy condition		
	August 1956	August 1957	November 1958
Trees with virus symptoms in November 1958 (49)	6·6	7·5	8·9
Trees without virus symptoms in November 1958 (48)	6·7	8·1	9·4

* Assessments of the extent of the canopy were made by the same observer, using the method described by Donald [10]. Trees with 1, ¾, ½, ¼, and 0 of a possible full canopy were given scores of 12, 9, 6, 3, and 0, respectively.

trees had been in virtually the same condition in 1956 and had shown a similar recovery after spraying, despite the complicating effects of virus. Indeed, there was no obvious difference between the trees with virus symptoms and the others without, and the condition of both groups was largely determined by their position in the farm. In the shaded portions, virtually all trees had recovered a full canopy of large, fully green leaves. Elsewhere, similar trees had made a less striking recovery and the leaves were small and chlorotic. Trees in the open also bore dead twigs and branches and bare shoots from which the leaves but not the stipules had fallen. This 'leafless twig' condition was not associated with virus infection and was common on unshaded trees in the whole area.

Discussion

The general condition of trees in the observation plots was largely determined by the incidence of capsids and the associated fungus, causing dieback, and only to a lesser extent by virus. This situation is general throughout Nigeria and the Cocoa Survey officers frequently find virus-infected farms in good condition; often similar to or better than others without virus but in the same locality. The general condition of the cacao in the abandoned areas of mass infection is also little different from that outside, where only scattered outbreaks occur. Clearly, the damage initiated by capsids is much more important and widespread than that caused by virus. Indeed, there is no evidence that typical viruses occurring in Nigeria will kill trees in well-maintained farms where capsids are controlled, or where these insects are not numerous. Under these conditions virus merely becomes a further debilitating factor in the general unthrifty condition of cacao in Nigeria.

Spraying against capsids has been introduced only recently in Nigeria and most farms are still infested, at a level which varies with site and with season. Well-maintained trees which are growing vigorously on good soil and in favourable conditions are little damaged and dieback is checked. Elsewhere, the trees may show severe dieback and pass into a progressive decline, as capsids continue to cause damage. This is accentuated by unfavourable climate, particularly when the canopy is broken and weeds invade the farms to compete for nutrients and soil moisture. By weakening the trees, virus apparently increases the probability of a decline and the rate at which this occurs. Thus the combination of virus and capsids is often lethal and has more harmful effects than either alone. The initial acute stage of virus infection when trees infected with the most virulent strains show conspicuous leaf symptoms, defoliation, and dieback, is apparently critical. Trees which are then heavily infested with capsids have less chance of survival than trees which have already passed into the relatively mild chronic phase. Environmental conditions are also important and it is likely that the effect of virus, like that of capsids [11], is partially determined by shade, soil, and other conditions.

The very great benefits to be derived from spraying against capsids are likely to become increasingly obvious in future years as more and more trees are sprayed. Indeed, extensive spraying provides a method of checking and even reversing any decline in production now caused by virus. Thus the present eradication measures against swollen-shoot disease [9, 12] may eventually be modified. However, any decision to do this cannot be taken lightly, since the most virulent strains may be lethal under atypical conditions or may have very serious effects on growth, yield, or longevity. Furthermore, therapeutic methods are not available for curing trees which become virus-infected, and unrestricted spread will inevitably result in unrelated strains occurring together and having cumulative effects.

Clearly, further work must be started to determine the precise conditions under which viruses kill trees. An approach on ecological lines is

indicated in which the action and interaction of pests and diseases is considered in relation to environment. Experiments with seedlings have already been started and reasonably uniform regularly planted trees will soon be available for more precise trials.

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SELECTION OF MERINO SHEEP: AN ANALYSIS OF THE RELATIVE ECONOMIC WEIGHTS APPLICABLE TO SOME WOOL TRAITS

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Summary

The economic weights applicable to qualitative characteristics of Merino wool have been estimated from data on fleece wool grown by fine, medium, and strong-woolled Australian Merinos. Australia-wide mean prices of commercial wool types, into which the fleeces had been classified, were used.

Multiple regression analyses were carried out, the dependent variable being the mean price for each fleece type, and the independent variables being the means for each type in eight fleece attributes (diameter, crimps per inch, staple length, and gradings of commercial count or quality number, character, colour, soundness, and handle).

Of these traits, length and colour had consistent effects on price, but these were small compared with the determination by count, which was of overwhelming importance and alone controlled nearly 80 per cent. of the variation in price. In the absence of count, either crimp or diameter assumed major importance, though both were less effective than count, crimp alone controlling 70 per cent. and diameter alone 63 per cent. of the variation in price. The remaining variables were unimportant as joint determinants of price and they could be deleted from the analysis without loss of ability to predict price, as could crimps and diameter when count was included. Count, length, and colour jointly controlled 91 per cent. of the variation in price.

The application of these findings to Merino breeding practice is discussed. The order of efficiency of three methods of selection in Merino sheep was estimated to be:

(*a*) selection for fleece weight and crimps per inch by means of an index;
(*b*) selection for fleece weight alone;
(*c*) selection for fleece weight holding crimps constant.

The differences in efficiency, however, were not large.

AT present, the relative importance of different wool traits in manufacture is not clearly known. The sheep-breeder can, however, estimate the wool users' specifications indirectly, as suggested by McMahon [1], by analysing the relation of market values to wool attributes. The information obtained can be used in sheep-breeding programmes in the form of economic weights for the calculation of selection indexes, such as that first developed for animal selection by Hazel [2]. In linear cases these weights are the simple coefficients of regression of price on each of the characters in question. Where other considerations prevent the use of selection indexes the information may still be used in other methods of selecting sheep for breeding. The present paper estimates appropriate economic weights for wool traits of Australian Merino sheep and discusses the results. Finally the application of the results to Merino breeding practice is considered.

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Material and Methods

Wool Data

In an experiment described briefly by Roberts and Dunlop [3], measurements and gradings of fleeces of different strains of Merino sheep had been made for a considerable number of animals over several years. The traits considered here were:

Diameter (microns)
Crimps per inch
Staple length (inches)
Commercial count (or quality number)
Character (14 grades, 14 = best)
Colour (7 grades, 7 = best)
Soundness (6 grades, 6 = best)
Handle (7 grades, 7 = best).

The gradings of character were based solely on visual appraisal of the uniformity and discreteness of crimping, while count was consciously assessed only on the frequency of crimping. The latter gradings were coded for computation as shown in Table 1.

TABLE 1. *Coding of Count Gradings*

Count	*Code*	*Count*	*Code*	*Count*	*Code*
56s	4	60/64s	10	70/74s	15
56/58s	5	64/60s	11	74s	16
58s	6	64s	12	74/80s	17
58/60s	7	66s = 64/70s	13	80s	18
60/58s	8			90s	19
60s	9	70s	14	100s	20

Fibre diameter was measured in mid-side samples. The methods of doing this and of measuring crimps per inch have been described by Turner *et al.* [4]. Staple length was measured directly on the shorn fleece.

Price Data

The Australian Wool Bureau [5] has described the wool types used for wartime appraisal and purchase of wool in Australia and currently recorded by the Bureau for all wools sold at auction in Australia. During the experiment an appraiser with war-time experience of this work designated each skirted fleece to a particular one of these types and at the same time made the subjective gradings of the wool traits referred to earlier. These type classifications form a link between the gradings and measurements of the experiment and the price data collected by the Bureau. The validity of this link depends on the correspondence between the type gradings of the appraiser and those of the appraisers employed by the Bureau and its predecessors. The Australian Wool Bureau Wool Statistical Service made available annual mean Australia-wide prices (free wool, clean on-the-floor basis) for the types covered by the experiment. These prices were supplied for all seasons from 1946–7 to 1953–4 inclusive except 1952–3.

Selection of Wool Types

Only those types were considered which were represented by a minimum of twenty fleeces, measured for all traits. Fleeces above twenty in any type were discarded at random. The wool types which were finally used in the analyses are listed in Table 2. In addition to these thirty-two types there were sufficient numbers in five crossbred types and two super spinners types. The crossbred wools brought considerably less than

TABLE 2. *Wool Types Studied*

Classification	*Wool types*
Good spinners' warp	36, 37, 38, 40, 41, 42
Good spinners' warp and half warp	43, 44, 45, 46, 48
Average spinners' and best topmaking warp	54P, 54, 55, 56, 56A, 57, 58, 59
Average spinners' and best topmaking warp and half warp	60P, 60, 61, 62, 62A, 63, 64, 64A
Average spinners' and best topmaking half warp	67, 69
Good topmaking, good to average length	78, 80
Good French combing	121P

Merino wools of adjacent counts while disproportionately high prices appeared to have been paid for the super-style types. All seven were discarded as probably introducing non-linearity. In all these types but one there were significant differences between actual prices and prices predicted from multiple regressions, thus showing that this action had been justified.

Price Means

The price of wool in some years since the war has been very high, and in order to give each year the same influence, prices have been expressed as percentages of the year mean instead of as actual figures.

It was considered that, in seasons of extremely high prices, little attention had been paid by buyers to quality differences which normally would carry considerable price differentials. This view was confirmed when rank correlations were computed between type price means for all possible pairs of seasons. It was found that 1950–1 and to a lesser extent 1947–8 and 1949–50 had prices which were not consistent with each other or the remaining years, each of which had high correlations (0·90 or more) with its fellows. The price data from the consistent seasons, 1946–7, 1948–9, 1951–2, and 1953–4, expressed on the percentage basis referred to above, were averaged for use in these analyses.

Statistical Methods

Multiple regression and correlation statistics in which price was the dependent variable and wool attributes the independent variables were calculated. In a multiple regression situation it is not possible to separate out discrete fractions of the variation in the dependent variable caused by the respective independent variables. However, an insight into the

relative importance of each independent variable may be obtained by deleting variables from the analysis in turn and observing how much of the variation in the dependent attribute is controlled by regression after each deletion. Much of the analysis is of this kind.

Results

'Normal' Seasons

The first analysis was of the multiple regression of the mean price of each type, expressed as a percentage for the four selected seasons, on the mean values in each type for the eight wool characteristics. The results of this analysis are given in Table 3 (*a*), which shows the simple regression coefficients which would be necessary for the computation of a selection index, and the corresponding standard partial regression coefficients, in which the weights which would be given to the independent variables in predicting price are all expressed on a comparable scale.

TABLE 3. *Regression of Mean Wool Prices on Wool Attributes*

	(*a*) *On eight attributes*		(*b*) *On six attributes*	(*c*) *On three attributes*
	Mean over four selected seasons (price as per cent. of mean)		*Mean over four selected seasons*	*Mean over four selected seasons*
Wool attributes	*Simple regression coefficient*	*Standard partial regression coefficient*	*Standard partial regression coefficient*	*Standard partial regression coefficient*
Count . .	3·55‡	1·07‡	0·98‡	0·98‡
Length . .	−8·98	0·25†	0·24†	0·23†
Character .	9·57‡	0·06	0·06	
Colour . .	13·66†	0·26*	0·27†	0·27‡
Soundness .	4·04	0·05	0·03	
Handle . .	17·94†	−0·10	−0·07	
Diameter .	−5·98‡	−0·11		
Crimps/inch .	3·08‡	−0·17		

Significance of regression coefficients: * = $P < 0.05$; † = $P < 0.01$; ‡ = $P < 0.001$

There is a heavy and highly significant dependence of price on count, while length and colour have real but less important effects; the remaining attributes seem of minor importance. A rather surprising factor is the negligible role played by character, a feature commonly stressed by breeders and wool classers. This finding supports the suggestion by Goldsworthy and Lang [6] that character may be unimportant. The minor role of soundness should be qualified by the fact that none of the types included in the analysis was a clothing wool. Thus, any unsoundness present was sufficiently discrete to affect only the allocation of the fleeces, via their effective lengths, among the types which would be combed in manufacture.

In this analysis, control of variation in price by the eight independent variables, as measured by the square of the multiple correlation coefficient, was 90 per cent.

As diameter and crimps per inch appeared to be unimportant in the control of price in the presence of count (with which both are highly correlated) the material of Table 3 was recomputed with these two variables deleted. This analysis, therefore, included a group of six traits all of which can be scored by speedy hand and eye methods. The standard partial regression coefficients are shown in Table 3 (*b*). Count is again of outstanding importance while length and colour give lesser, but still real, assistance in the prediction of price. The fraction of the variance in price controlled by the independent variables was virtually unchanged at 91 per cent. (The apparent anomaly of increased control with fewer variables is a statistical artefact.)

A Highly Competitive Season

It is interesting to record that in analyses covering the data from the season of record prices, 1950–1, the control of price by the variables considered here was reduced by approximately one-third, suggesting that, in such seasons of fierce competition, there is much less reference than usual to the normal standards of wool quality.

The Main Attributes

Having shown that diameter and crimp may be omitted without appreciable loss of control in predicting price, the next step is to consider whether any of the remaining variables may be omitted. Count has been consistently of major importance as have length and colour to a lesser degree. The other variables—character, handle, and soundness—have been shown to have little influence on price in a multiple regression situation. The data were, therefore, reanalysed following the deletion of these three independent variables.

The results of this analysis are shown in Table 3 (*c*). The regression coefficients remain practically unchanged, with all three variables playing a significant role in the prediction of price; count, as usual, being overwhelmingly important. The most striking feature, however, comes from calculation of predictive ability where it is found that the three variables give as good control as did the equivalent regression with six variables in Table 3 (*b*), the fraction of the variance in price controlled being 91 per cent. in each case.

The marked importance of count throughout suggests that the control of price by count alone should be of interest. The square of the simple correlation is the appropriate figure and it shows that count alone controlled 79 per cent. of the variation in mean prices for the four selected seasons.

Where data are available on all eight independent variables, the process of deleting variables, which has been followed, is a logical one. However, the very high correlation between crimp and count in these group mean data (0·96) and the high correlations between these variables and diameter (−0·85 and −0·86), suggest that the importance of crimp and diameter, in the absence of the subjective grading of count, might be considerable. Moreover, there appears to be growing evidence [7] that crimp frequency as well as diameter is important in manufacturing

processes. Consequently multiple regression analyses were carried out, using the same price data as before, but with these two variables successively replacing count in the six- and in the three-variable analyses. In addition, their joint effect has been considered in an analysis with two other independent variables. The percentage control of variation in price in these analyses and the equivalent percentages reported earlier appear in Table 4, together with the percentage control of price achieved by each of these two variables alone. It can be seen from Table 4 that, in the absence of count data, crimp, in conjunction with either five or two

TABLE 4. *The Percentage Control of Price by Combinations of Independent Variables*

Eight variables	*% control*	*Six variables*	*% control*	*Four variables*	*% control*	*Three variables*	*% control*	*One variable*	*% control*
Count Crimps Diameter Length Colour Soundness Character Handle	90	Count Length Colour Soundness Character Handle	91			Count Length Colour	91	Count	79
		Crimps Length Colour Soundness Character Handle	80	Crimps Diameter Length Colour	82	Crimps Length Colour	81	Crimps	70
		Diameter Length Colour Soundness Character Handle	67			Diameter Length Colour	66	Diameter	63

other independent variables, can give reasonably good control of variation in price, though it is less effective than count. Diameter on the other hand, when used in this way, gives considerably less information about price. When both are combined with length and colour, they give virtually no more control of price than crimp, length, and colour. Apparently crimp and diameter do not completely determine the price-governing characteristics of count.

When considered alone, each of the three variables—count, crimp, and diameter—gives appreciable control of variation in price in descending order of importance. In each of the additional multiple regression analyses referred to above (but not reported in tabular form) the importance of diameter or of crimp, as judged by the relative sizes of the standard partial regression coefficients, was very much greater than that of any of the other independent variables. The only exception was when crimp and diameter were both considered, together with colour and length. In this case, as might be expected, crimp was outstandingly

important, while the influence of diameter was equivalent to that of length and colour.

Discussion

It is clear from the present results that if price data are to be used as a guide by the breeder, selection on the qualitative aspects of the fleece must be based mainly on count (or on crimp frequency). As this trait is probably genetically negatively correlated with fleece weight [8], selection by the index method is indicated. However, it has not yet been possible to construct adequate selection indexes for breeding Merino sheep in Australia. This has been due in part to the costs of measuring some characters on large numbers of animals. In the main it has been due to a lack of economic weights to apply to important traits and of good estimates of the genetic correlations between them. Nevertheless, enough is known about the heritability of these characters to suggest that most of them would respond to mass selection. Consequently a number of schemes, all essentially variants of the 'half classing' method [9, 10, 11, 12], have been devised and put into practice. All these are applications of the method of independent culling levels [13], and in each an initial selection is made on a number of loosely defined wool and body traits. This 'primary culling' is followed by a secondary selection mainly on the basis of fleece weight, though the final selection may be influenced by other wool traits such as fineness, colour, and length. However, the amount of selection which should be done at various levels of this process has not been adequately investigated. This may be because the theory of independent culling levels becomes complex when characters are correlated, and has only been explored for uncorrelated traits [13].

Because of its simplicity and relatively low cost the independent-culling-levels approach is likely to be retained at the flock level and in the selection of females. It is therefore important that the method should be closely examined, first, so that the optimum amount of culling can be done in each of its stages, and second, so that its efficiency may be compared with index selection to determine just how much progress is being sacrificed by using this alternative in the more important process of ram selection.

In all these schemes of the 'half-classing' type the main aim is to increase fleece weight while at the same time holding count between specified levels or above some lower limit. Morley [8], using a set of phenotypic and genetic parameters, estimated the improvement in clean fleece weight where selection is for weight and crimp number in such a way as to ensure that the latter trait does not change. He expressed this improvement as a fraction of that expected where selection is based solely on clean fleece weight.

Now that estimates of economic weights are available for these traits it is possible to make this comparison in terms of $\bar{H}$, the aggregate genetic gain in terms of money [13] and to compare the progress on these two bases with that possible where an index is used which gives optimum attention to each trait. The parameters used by Morley in his computations differed markedly in some cases from his own estimates.

Consequently, comparisons similar to those discussed above, but based on the best available estimates, could be some guide to selection practice. Estimates of progress under these various conditions have been made and are shown in Table 5 based on (*a*) the estimates of parameters used in Morley's computations of progress, and (*b*) what appears to be Morley's best estimates of these parameters. (In his notation these are:

$$P_{11} = 1{\cdot}0,\ P_{22} = 3{\cdot}5,\ P_{12} = -0{\cdot}6,\ G_{11} = 0{\cdot}47,\ G_{22} = 1{\cdot}65,$$
$$G_{12} = -0{\cdot}47.)$$

The same economic weights are applicable, where necessary, to (*a*) and (*b*) above. As the simple regression coefficients of Table 3 (*a*) are derived from price data varying round a mean of 100 pence per pound we may use 100 as the economic weight applicable to clean fleece weight. The economic weight for crimps must equal the product of the pertinent

TABLE 5. *Expected Genetic Change under Three Methods of Selection and Two Groups of Parameters*

Parameter group	1[a]			2[b]		
Change in	*Clean-wool weight (lb.)*	*Crimp number (per inch of staple)*	*H (pence)*	*Clean-wool weight (lb.)*	*Crimp number (per inch of staple)*	*H (pence)*
Selection by index . .	0·49	−0·13	45·6	0·43	−0·28	36·4
Selection holding crimp number constant . .	0·44[c]	0	44·2	0·35	0	34·6
Selection on clean fleece weight alone . .	0·50	−0·20	45·1	0·47	−0·47	35·4

[a] Calculation based on parameters used by Morley [8].
[b] Calculation based on the 'best estimates' of parameters by Morley.
[c] The value of 0·35 calculated by Morley appears to be incorrect following an error of sign.

regression coefficient and the average clean-fleece weight (Rae, 1955, personal communication). This is approximately $3{\cdot}08 \times 8{\cdot}0 = 24{\cdot}64$. The genetic changes shown in Table 5 are those resulting from a selection differential of one standard deviation in the index or trait under selection in each case.

Table 5 shows, of course, the maximal efficiency of the index method. However, a much more interesting and important finding is that the exceedingly simple and practicable method of selecting on clean-fleece weight alone is almost as efficient as the index method. This results from price trends of recent years, where weight has been several times as important as quality number in determining the value of a fleece. Thus selection for an additional character of minor importance is relatively unrewarding. It is not surprising, therefore, that there is a drop in efficiency when restrictions are placed on changes in crimp number.

The precepts emphasized by these results in comparison with current extension practice are that recommended selection procedures should be based on adequate estimates of the relevant parameters, and that

arbitrary decisions and restrictions, irrespective of the plausibility of supporting arguments, are, in fact, arbitrary. It could, of course, be suggested that, if selection on weight alone or by an optimum index were recommended to, and intensively carried out by, all Merino woolgrowers, the economic weights might eventually be changed by the scarcity of highly crimped wools. This does not seem sufficiently imminent to be of early importance, though any selection programme should allow for the periodic reappraisal of the genetic and economic parameters concerned.

While the general conclusion drawn in this paper about the relative importance of the various wool traits in determining price, and their relevance to current selection practice, appear to the writers to be soundly based, nevertheless several qualifications must be mentioned. First, the effect on prices, of vegetable matter contained in wool, has not been considered, for the prices used in these analyses were on a clean basis for free wools. The range of fault in the present types was from free or nearly free down to light (B) burr as described by the Australian Wool Bureau [9]. It is considered that the influence of this fault would have been marked only if the range of wool types had also included wools with heavy burr. Further, the conclusions reached here are based on fleece wool only. It seems more than likely that similar differences in non-fleece wools would be reflected in smaller price changes. The situation in such wools remains to be explored.

Second, these analyses have been carried out over a range of wools from most of the important strains of the Australian Merino and thus express the preferences of the trade reasonably well. However, it is statistically possible for the regressions within strains, each of which would only cover limited portions of the type and count range, to be different from the overall regressions. Roberts, Ryan, and McMahon (New South Wales University of Technology, unpublished data, 1955) examined the relations of length, count, colour, and character to prices realized within individual flocks of medium- and fine-woolled Merinos. In most cases their regressions confirmed the general order of the conclusions reached here about the relative importance of these variables.

Third, it is possible that the presence of a considerable quantity of medium and fine Merino wool (in terms of crimp frequency) in the Australian clip has general beneficial effects on buyer representation and on price levels in the Australian market, which are not reflected specifically in the price differential of finer wools. If this is real and important, any long-term lowering of the quality number of Australian Merino wool would be contra-indicated. Economic research into such a topic seems likely to be complex, but is nevertheless required to decide this issue.

Finally, the present analyses were unable to take cognizance of whether or not the attention given by the trade to the various features of wool is correctly related to their importance in manufacturing processes. This is a question which can be answered only by technological research. The wool-growing industry which is facing competition from alternative materials should logically have the value of the various wools it produces

determined by their suitability for manufacturing requirements. Thus the need for technological research into the relative importance of various wool traits in manufacture can hardly be overstressed. However, it seems likely that the time required for such research, and for its application to be expressed in the price structure of the notably conservative wool trade, would be considerable. Thus, results obtained by the present methods will probably be useful in guiding breeding procedure for some time to come, within the range of wools studied here.

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SEED-BED PATHOGENS OF GROUNDNUTS IN THE SUDAN, AND AN ATTEMPT AT CONTROL WITH AN ARTIFICIAL TESTA

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Summary

Up to 75 per cent. of groundnut seed planted at the Sudan Central Rainlands Research Station was liable to destruction before emergence of the shoot; mostly from fungal attack. The principal pathogens were *Rhizopus* spp., *Aspergillus niger*, and *A. flavus*, the Rhizopus being very active in destroying ungerminated seed, and the Aspergilli attacking mostly the germinated seed. *A. niger* also occurred as crown rot on emerged seedlings.

Damage to the seed coat or the cotyledon increased the liability to attack by these fungi. An artificial seed coat of methyl cellulose was applied to both damaged and intact seed, and appeared to reduce the incidence of *A. flavus* but had no apparent effect upon Rhizopus infection, which remained largely uncontrolled.

THE optimum population for groundnuts at the Central Rainlands Research Station, Tozi, in the Blue Nile Province of the Sudan, was found to be between 75–80,000 plants/feddan.[1] At first it was impossible to achieve such high populations by ordinary planting methods, and apart from the purely mechanical difficulty of planting such large numbers of delicate seeds by machinery, a large proportion of planted seed failed to emerge. Such losses varied between 20 and 75 per cent. of the seed planted, according to the soil moisture conditions at the time of planting.

Similar losses had been recorded in Tanganyika [2] where the main causes of loss were *Rhizopus* spp., notably *R. stolonifer* Ehren. ex Fr., *R. oryzae* Went & Gerl., and *R. arrhizus* Fischer, *Aspergillus niger* van Tiegh., and *A. flavus* Link. It was presumed that these would be the main pathogens in groundnuts in the seed-bed in the Sudan, although soil and climatic conditions were widely different. Some control was achieved by the use of fungicidal seed dressings, but this was far from complete [3] and was much less than with similar dressings in Tanganyika.

During this work, it appeared that an intact testa was a strong deterrent to fungal attack, particularly by *Rhizopus* spp. It seemed possible that, where the testa had been damaged at the time of shelling or later, an artificial testa might be applied which would reduce losses from Rhizopus attack without recourse to chemical fungicides.

Causes of Loss in the Seed-bed

The first field experiment to analyse the causes of seed-bed loss was carried out in 1953: groundnuts were planted by hand in a field which

[1] 1 feddan = 1·038 acres.

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had borne groundnuts in the previous season, and which might therefore be expected to have a high infection potential. The rows were marked so that seed could be recovered at intervals of time and examined for damage. There were four replications of each date of such recovery, in randomized blocks, and there were two dates of planting, the first, in dry soil, on 1 July; the second, 19 days later, in wet soil which had had much rain in the meantime. For the second date of planting, the plot size was increased, at the expense of the number of dates of recovery, since in the first planting the plots had been too small to allow of a reasonable standard error with the large number of categories of infection. The plots were split, half the seed being dusted with the organo-mercurial Agrosan GN at a rate to give 1 part Hg per 50,000 parts by weight of seed.

The variety used was Natal Common, one of the upright bunch types in the Valencia/Spanish group of Bunting [4] with small seeds of high oil- and protein-content, a short growing season, and no period of dormancy in the seed. This variety, or Barberton, a similar variety of common origin, were used throughout the following work.

The earlier-planted seed was dug up after 2, 5, 7, 12, 16, and 24 days, by which time emergence was complete. In the later planting only four dates of recovery were possible, largely because heavy rain made the soil (a very heavy montmorillonitic clay), impossible to work for several days at a time.

The results of the analysis of causes of damage to the seeds appear in Tables 1 and 2. In each case the principal pathogens were the same: *Rhizopus* spp., *Aspergillus niger*, and *A. flavus*, with a very small proportion of infections by other fungi, mainly several species of Penicillium and Alternaria. These latter fungi were not found in constant association with damaged seed and appeared not to be primary pathogens.

Excluding the effects of the organo-mercurial seed dressing in the later planting, the obvious difference between the dry and wet plantings was the degree of infection by the various species, particularly by Rhizopus.

It has been noted elsewhere [2] that the ability of Rhizopus to infect groundnut seed declines rapidly after germination. In fact, at Tozi, Rhizopus could not be made to infect undamaged cotyledons of germinated seed. This is at variance with results obtained with *R. stolonifer* in Tanganyika where a small number became infected up to the fourth day after germination. Both spore suspensions and active mycelium were used; the latter occasionally attacked the split testa. Rhizopus was never found on the hypocotyl.

In the dry planting (Part I of Table 1) there was neither germination nor fungal attack before 5 days after planting, when the first fungal attack occurred—a Rhizopus infection of germinated seed. At this stage the soil was still dry except at the surface (there had been a little rain on the fourth evening after planting). Appreciable rain followed, and by the seventh day the soil was moist to some depth; over half the seed had germinated. Of that which had not, over 30 per cent. was infected with Rhizopus. The other main attackers, *Aspergillus niger* and *A. flavus*, had begun to attack ungerminated seed, but there were as yet no

TABLE 1. *Groundnut Losses in Seed-bed, as Percentage of Total Planted*

Days to recovery of seed or seedlings	Seed or seedlings recovered				Lost	Condition of recovered seed or seedlings				Insect damaged
	Ungerminated	Germinated, not emerged	Emerged	Total		Healthy	Fungal infected			
							Ungerminated	Germinated	Total	
I. *First date of planting, 102 untreated seeds/plot*										
2	100·0	0·0	0·0	100·0	0·0	100·0	0·0	0·0	0·0	0·0
5	97·0	0·0	0·0	97·0	3·0	95·1	1·0	0·0	1·0	1·0
7	34·3	53·9	0·0	88·2	11·8	59·8	25·5	0·0	25·5	2·9
12	21·6	68·6	0·0	90·2	9·8	20·6	12·7	32·3	45·0	2·9
16	17·6	38·3	31·7	87·6	12·4	12·7	13·3	27·4	40·7	2·9
24	9·8	4·9	21·5	36·2	63·8	24·4	4·9	5·9	10·8	1·0
II. *Second date of planting, 220 seeds/plot, half untreated* (O), *half dressed with Agrosan* (A)										
5 O	10·0	60·5	0·5	70·9	29·1	29·5	26·8	10·0	36·8	4·5
A	7·7	53·6	0·5	61·8	38·2	30·0	23·2	7·7	30·9	0·9
10 O	7·3	3·6	43·6	54·5	45·4	27·3	12·3	7·3	19·5	7·7
A	5·5	7·3	47·3	60·0	40·0	26·4	12·3	5·5	17·7	15·9
13 O	8·2	5·5	38·2	51·8	48·2	21·8	16·8	8·2	25·0	6·8
A	10·0	3·6	40·0	53·6	46·4	27·3	5·5	10·0	15·5	10·9
25 O	0·0	0·0	30·9	30·9	69·1	27·3	0·0	0·0	0·0	3·6
A	0·0	0·0	21·8	21·8	78·2	20·0	0·0	0·0	0·0	1·8

TABLE 2. *Analysis of Seed-bed Pathogens of Groundnuts. Infected Seed or Seedlings as Percentage of Total Recovered. UG = Ungerminated. G = Germinated*

Days to recovery of seed or seedlings	Rhizopus *spp.* alone		A. niger, *and* Rhizopus		A. niger, A. flavus, *and* Rhizopus		A. niger *alone*		A. flavus *alone*		A. niger *and* A. flavus		*Other fungi*	*Crown rot*	*Total infections*		
	UG	*G*	*UG*	*G*	*UG*	*G*	*UG*	*G*	*UG*	*G*	*UG*	*G*	*UG*	*G*	*UG*	*G*	*Total*
I. *First date of planting. Untreated seed*																	
2 . . .	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
5 . . .	1·1	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	1·1	0·0	1·1
7 . . .	15·6	0·0	0·0	0·0	0·0	0·0	3·0	0·0	6·7	0·0	0·0	0·0	3·3	0·0	28·6	0·0	28·6
12 . . .	1·4	1·4	1·4	1·4	9·8	18·2	1·4	12·6	2·8	8·4	1·4	4·2	0·0	0·0	18·2	46·2	64·4
16 . . .	1·6	1·6	1·6	1·6	9·6	14·4	1·6	4·4	3·2	4·8	1·6	3·2	6·4	4·8	25·6	39·6	65·2
24 . . .	0·0	0·0	2·7	0·0	2·7	2·7	2·7	2·7	2·7	0·0	0·0	0·0	2·7	10·8	13·5	16·2	29·7
II. *Second date of planting. Half untreated seed* (O), *half seed dressed with Agrosan* (A)																	
5 O . .	4·5	12·2	1·3	2·6	5·1	5·8	0·0	5·1	0·0	7·7	0·0	4·5	3·2	0·0	14·1	37·9	52·0
A . .	6·6	14·0	0·0	4·4	3·7	2·2	0·0	11·8	0·0	1·5	0·0	3·7	2·2	0·0	12·5	37·6	50·1
10 O . .	4·2	1·7	0·0	0·0	0·8	0·0	0·0	8·3	2·5	7·5	0·0	0·8	5·8	4·2	13·3	22·5	35·8
A . .	3·8	1·5	0·0	1·5	0·0	0·8	0·0	10·6	0·0	1·5	0·0	0·8	4·5	3·8	8·3	20·5	28·8
13 O . .	0·0	0·0	0·0	0·0	3·5	0·0	0·0	10·5	6·1	10·5	0·0	7·0	6·1	4·4	15·7	32·4	48·1
A . .	1·7	0·8	3·4	0·8	0·0	0·0	0·0	5·9	3·4	0·8	2·5	0·0	7·6	1·7	18·6	10·0	28·6
25 O . .	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
A . .	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0

mixed infections. Subsequently, the pattern of infection became less clear, as most of the infections were mixed. Rhizopus on its own declined very rapidly as germination proceeded, although the total number of infections of which Rhizopus was a part rose sharply, doubling between the 7th and 12th days. Over half its incidence was on germinated seed, but there is little doubt that such infections began before the seed had sprouted. At 16 days the situation was unchanged, but by the 24th day there were no infections by Rhizopus alone. A small proportion of the remaining seed was ungerminated, and of this a mixed infection of Rhizopus, *A. flavus*, and *A. niger* accounted for half.

Rhizopus is a very rapid destroyer of groundnut seed, particularly that of high protein and oil content such as Natal Common. In laboratory conditions, using seed planted in wet sand/soil mixtures, it was found that it could reduce a groundnut seed to a pulp almost indistinguishable from the surrounding black soil within 24 hours. It seems probable that much of the progressively increasing loss without trace of the seed, recorded in Table 1, is due to this rapid dissolution, and by the 24th day there was probably no ungerminated seed susceptible to Rhizopus attack which had not already been destroyed by it.

In the second, wet, planting (Part II of Table 1) germination was rapid, in soil already containing active fungi. By the time of the first inspection (earlier recovery was prevented by wet soil conditions), over half the seed had already germinated, and nearly half of all the seed had fungal infections of some sort. Rhizopus on its own was found on 15 per cent. of the seed, and in association with the Aspergilli on a further 15 per cent. Once again, rather more than half this seed had germinated, presumably after the infections with Rhizopus had taken place. By the 10th day germination was more or less complete, and Rhizopus appeared on a few seeds, most of it being confined to those which remained ungerminated, of which it accounted for over half. By the 13th day no pure Rhizopus infections were found, although it occurred in mixed infections with the Aspergilli on a third of the still ungerminated seed. The number of seeds lost without trace was very great in this second planting, increasing rapidly as time went on. It may be assumed, again, that Rhizopus accounted for much of this loss.

The difference in incidence of the Aspergilli, between the two dates of planting, was less marked. In the drier planting both species occurred more often as mixed infections, either together, or along with Rhizopus, or, in the case of *A. niger* only, with Rhizopus alone.

Aspergillus flavus was the next fungal attacker of the seed, after Rhizopus. It was more often found upon germinated seed, and it can attack seed after it has germinated, although it appeared to do so with difficulty unless the inoculum included active mycelium. However, if *A. flavus* fails to destroy a seedling before the shoot is fairly well established and growing vigorously, it appears to lose its capacity to do so, and is restricted to its original site of infection, making slow progress on the shrivelled remnant of the cotyledon once the shoot has emerged. As in Tanganyika, it was found in rare cases to cause a form of crown rot by attacking the hypocotyl. Its general incidence was higher than on

groundnut seed in Tanganyika, which may be due to the much more alkaline soil at Tozi. Its action was slower than that of Rhizopus, but it can cause the complete decomposition of the seed in the course of 4–7 days.

Pure infections of *A. flavus* were found 7 days after planting in the first, dry, planting: by the 12th day it was found in well over two-thirds of all infections, mostly mixed with *A. niger* and Rhizopus. By the 16th day the proportion was unchanged, although the overall number of seeds and seedlings infected was lower, and on the 24th day after planting, *A. flavus*, whilst still present both as a pure infection and in complex with *A. niger* and Rhizopus, was reduced to very small numbers.

For the second date of planting *A. flavus* occurred in much the same proportions as in the first, dry, planting, at similar stages of germination. At first it appeared mostly in complexes with both *A. niger* and Rhizopus, the proportion of pure infections of *A. flavus* alone increasing at the later dates. It was remarkable that in these results *A. flavus* and Rhizopus were never found alone together, although in subsequent field trials and in laboratory tests, such an association was not infrequent. Some explanation may lie in the behaviour of *A. niger*, which was unusually active in the conditions of this experiment.

It appears that, under normal circumstances, Rhizopus is the first invader; *A. flavus* was slower to start its attack (although there is nothing to suggest that it requires any beginnings of germination in the seed before it can do so), and it continued to attack for a longer period. *A. niger* rarely attacked ungerminated seed by itself, and was usually found at a fairly late stage after germination. In the conditions of this experiment, possibly because germination of the seed was rapid once it started, causing a telescoping of the phases of attack, *A. niger* appeared to occur earlier, at about the same time as *A. flavus*.

A. niger was present on ungerminated seed at day 7 in the dry planting: this was unusual, but it was of much less importance than *A. flavus* at this stage. By the 12th day it was the major component of fungal complexes, and was also found by itself on some 15 per cent. of the seed or seedlings. This pure infection was much reduced by the 16th day, but *A. niger* continued to be a component of the complexes attacking another 30 per cent. or more. The number attacked by *A. niger* remained fairly constant to the 24th day, although its incidence as part of a complex was very much reduced by this time, probably, as explained above, due to the small number of seed recovered by this date. In the wetter planting, *A. niger* was more important throughout as a solitary attacker: it occurred, as before, in complexes, but to a less extent.

In both plantings crown rot due to *A. niger* infection of the hypocotyl was found on emerged seedlings: it is not, properly, a part of the seedbed loss before emergence, but is included because it is a continuation of infections causing such loss, and, as shown by Gibson [5], the difference between observed crown rot and pre-emergence loss due to *A. niger* is only a matter of the rate of development of the hypocotyl and the distance which it has to travel through the soil before emergence.

A comparison between the relative incidence of the species in the

second date of planting, with and without the organo-mercurial seed-dressing Agrosan GN, shows that, under those conditions, the fungicide was having little effect upon total infections as long as Rhizopus and *A. niger* remained the principal pathogens. There is a suggestion, so small as to be most probably fortuitous, that the incidence of Rhizopus infections alone increased where Agrosan is applied; this may be due to the suppression of some other component of a fungal complex of which only Rhizopus is unsusceptible to mercurials. There was, however, no suggestion of control of Rhizopus by the mercurial. This is markedly at variance with results obtained with the same seed dressing in Tanganyika [2], where Rhizopus was considerably reduced by it. It is similarly at variance with expectations derived from field trials of the same seed dressing, where very good control of pre-emergence losses was obtained [3].

The incidence of *A. niger* increased slightly where the mercurial was applied at the 5th and 10th days after planting; in the latter case the increase was very slight. At 13 days the incidence of *A. niger* was slightly reduced by Agrosan, both as a pure infection and as a component of mixed infections. The incidence of crown rot was similarly decreased.

From these data there is no real sign of the anomalous effect of organo-mercurials in increasing attack by *A. niger*, as explained by Gibson [5]. There was, however, no doubt that such an effect was common in the Sudan, being recorded in field observations of crown rot on numerous occasions [1].

A series of laboratory trials was begun to explore further the effects indicated by the field trial. They were all alike, with Natal Common seed buried at shallow depth in tins of soil, with which one-third (by volume) of sand had been mixed to render recovery easier.

Except that Rhizopus was slightly controlled by mercurial seed dressing, the results of the field trial were confirmed. By reducing the moisture content of the soil it was possible to reduce the rate of germination and lengthen the periods during which each of the principal pathogens was the major component of attack.

Application of an Artificial Testa

It had been found in Tanganyika [2] that damage to the seed coat or cotyledon resulted in increased susceptibility to fungal attack in the seed-bed. This was confirmed at Tozi by laboratory tests, in which seed was deliberately damaged, and in the field during the course of a test of groundnut planting machinery which is reported elsewhere [6]. In this field trial, three grades of seed were used, with or without a dressing of Agrosan GN. The three grades of seed were those found commonly after passage of seed through mechanical decorticators, viz. (1) entirely undamaged; (2) completely without the testa, but without damage to the cotyledons; (3) with a part of the testa, and the cotyledon abraded. A fourth grade of seed (split, with or without the testa adhering) was not included, as it is rare for such seed to give an emerged seedling in field practice.

The emergence of seedlings from the three grades is given in Table 3. The best emergence was from intact seed, followed by skinned seed with undamaged cotyledons. Abraded seed gave a considerably less emergence, little more than half that of intact seed. The improvement in emergence with a dressing of Agrosan was statistically significant on intact or abraded seed. The anomalously high emergence of undusted skinned seed is unexplained, and probably fortuitous.

Damage to the seed coat is inevitable with mechanical handling, whether in decortication, seed dressing, planting, or movement in store. If the presence of a seed coat preserves the seed from fungal attack; and, by inference (since it is Rhizopus which attacks the seed when the testa is still intact, before being ruptured by the emerging radicle), if it controlled Rhizopus attack, there might be considerable advantage in applying an artificial seed coat before planting.

TABLE 3. *The Effect of Mechanical Damage of Seed on the Establishment of Groundnuts*

Treatment	*Populations 10 days after planting Mean number per plot*			
	Whole seed	*Skinned seed*	*Abraded seed*	*Mean*
	SE. ±1·35[a]			SE. ±0·78[b]
Dusted with Agrosan	24·7	19·3	15·3	19·8
Undusted	20·1	21·5	11·7	17·8
	SE. ±0·96[c]			
Mean	22·4	20·4	13·5	18·8

Least significant differences:		a	b	c
	$P = 0{\cdot}05$	3·9	2·3	2·8
	$P = 0{\cdot}01$	5·3	3·1	3·8

Such a seed coat must be permeable to water, and resilient as well as tough. It might be possible to include fungistatic chemicals therein; or it might be found that the intact artificial seed coat made such chemicals unnecessary.

After consultation with the Plastics Division of Imperial Chemical Industries Ltd., and with Plant Protection Ltd., the latter firm kindly supplied a quantity of methyl ethyl cellulose, which was used as an artificial testa.

Numerous preliminary trials led to the following technique: seed was soaked in a 2·9 per cent. suspension of the plastic in distilled water, using just sufficient quantity for the seed to take it up on the surface (about 30 ml. to 100 gm. seed), and dried in a current of warm air. Seed for the controls in the experiments was treated in the same way, but using plain water. In the laboratory this treatment had no apparent effect upon the germinating capacity of the seed, although unfortunately the rate of germination was not investigated. In some cases a quantity of thiram (tetramethylthiuramdisulphide) was incorporated into the plastic suspension.

Seed in each of the above three categories was submitted to the following treatments: (*a*) a plastic seed coat was applied as above; (*b*) the same, but including a dressing of thiram at 0·01 per cent. on the weight of seed; (*c*) uncoated seed; (*d*) uncoated seed dressed with thiram at the same rate as for the coated seed. All was planted by hand in land which had previously borne groundnuts, great care being taken not to damage the artificial seed coat. The layout was in randomized blocks with six replications.

None of the skinned seed emerged, whether treated or not. The emergence of the other two grades of groundnuts is shown in Table 4.

TABLE 4. *The Effect of an Artificial Seed Coat and Seed Dressing on the Establishment of Groundnuts*

Treatments	*Maximum population per plot, after 13 days*		
	No thiram	*With thiram*	*Total*
Whole seed			
Not coated	21	64	85
Coated	11	45	56
Total	32	109	141
Abraded seed			
Not coated	20	72	92
Coated	3	33	36
Total	23	105	128
Totals			
Not coated	41	136	177
Coated	14	78	92
Total	55	214	269

The thiram seed dressing increased emergence about fourfold, whilst the artificial testa reduced it by half. This reduction by the artificial seed coat was totally unexpected, as there had been no apparent ill effects in laboratory tests. An immediate investigation was made by digging up one replication of the experiment 14 days after planting, leaving the remaining five replicates for further observation, which, however, revealed nothing further. Nearly two-thirds of the seed planted was recovered, and most of it was ungerminated. Nearly all the infections present were of *Aspergillus flavus*, which was worst on the damaged grades of seed, and was reduced by the thiram dressing. The artificial seed coat seemed to have reduced the incidence of *A. flavus* slightly, but there was nothing to show what might have caused the reduced emergence.

Using the remainder of the seed prepared for the experiment, the treatments were repeated in laboratory conditions, in tins of soil from the same site, fifty seeds being planted in each treatment. Three days after planting the seed were recovered, very few being lost, although some Rhizopus-infected seed were almost unrecognizable in the black soil.

TABLE 5. *The Effect of an Artificial Testa, and of Seed Dressings, on Fungal Infections of Groundnuts 3 days after planting. UG = Ungerminated. G = Germinated*

Treatment	Seed recovered	Ungerminated	Healthy seed			Infected seed							
						Rhizopus alone		A. flavus *alone*		*Rhizopus* and A. flavus		*Other fungal complexes*	
			*UG	G	Total	UG	G	UG	G	UG	G	UG	G
1. *Seed coated: dressed with thiram*													
Whole seed	49	3	0	36	36	2	8	0	2	1	0	0	0
Abraded seed	50	32	0	4	4	32	14	0	0	0	0	0	0
Skinned seed	49	48	0	0	0	43	1	0	0	5	0	0	0
Total	148	83	0	40	40	77	23	0	2	6	0	0	0
2. *Seed not coated: dressed with thiram*													
Whole seed	52	2	1	29	30	1	7	0	10	0	2	0	1
Abraded seed	50	32	0	18	18	16	15	0	1	0	0	0	0
Skinned seed	50	45	0	0	0	42	5	0	0	3	0	0	0
Total	152	79	1	47	48	59	27	0	11	3	2	0	1
3. *Seed coated: no thiram*													
Whole seed	49	18	0	6	6	14	17	0	2	2	8	0	0
Abraded seed	51	36	0	4	4	25	11	0	1	7	3	0	0
Skinned seed	46	46	0	0	0	43	0	0	0	3	0	0	0
Total	146	100	0	10	10	82	28	0	3	12	11	0	0
4. *Seed not coated: no thiram*													
Whole seed	50	10	0	9	9	7	13	0	11	3	7	0	0
Abraded seed	47	15	0	2	2	9	24	0	0	6	4	0	2
Skinned seed	47	37	0	0	0	36	8	0	0	3	0	0	0
Total	144	62	0	11	11	52	45	0	11	12	11	0	2
Totals													
Coated	294	183	0	50	50	159	51	0	5	18	11	0	0
Not coated	296	141	1	58	59	111	72	0	22	15	13	0	3
With thiram	300	162	1	87	88	136	50	0	13	9	2	0	1
No thiram	290	162	0	21	21	134	73	0	14	24	22	0	2
Grand Total	590	324	1	108	109	270	123	0	27	33	24	0	3

The analysis of the infections of the seed is found in Table 5, where it is apparent that the main difference between the seed with and without the plastic seed coat is that the latter germinated much more slowly: 183 out of 294 seeds with the artificial testa were ungerminated at 3 days, compared with 133 out of 296 seeds without the plastic coat. The discrepancy in the total number of seeds is due partly to incomplete recovery, partly to two treatments having had more than the intended 50 seeds planted, in error. The reason why so many of the seeds never germinated was Rhizopus infection: 159 of the ungerminated seed with plastic coats were infected, compared with 111 of the others. Once again, the artificial seed coat seemed to have reduced infections by *A. flavus* by a small amount: infections by *A. niger* at this stage were negligible.

The thiram treatment reduced the attack by a complex of *A. flavus* and Rhizopus, but, for some unknown reason, did not affect the incidence of either fungus alone. Most of the Rhizopus attack was on ungerminated seed, but of the germinated seed, that of the abraded group seemed to be more attacked by Rhizopus than the rest. In some cases this appeared to be due to local necrosis at the point of abrasion, which may have allowed the establishment of Rhizopus more or less saprophytically, even after actual germination had begun.

The results of this trial confirm the previous conclusions that Rhizopus is the most important of the pathogens, and demonstrate the necessity for ensuring the most rapid germination possible.

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technique is to avoid the seed having to remain ungerminated in the soil once the soil is moist.

No investigations were made on other varieties of groundnuts which have a seed dormancy, since these were not in common use in the Rainlands, but it would be important to find whether this dormancy affected fungal attack if the seed were sown out of season (as, for example, for extra crops under irrigation). One such variety in Tanganyika [2] had shown marked differences in susceptibility to the three main pathogens.

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SOME ECONOMIC ASPECTS OF MECHANIZED COTTON FARMING AT NAMULONGE, UGANDA

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Summary

A farm-costings study was started in late 1956 at the Cotton Research Station, Namulonge, in the Buganda province of Uganda. The station lies in the bimodal rainfall belt of East Africa, and there are two cropping seasons in each year. The principal crops are groundnuts and maize in the first rains, and cotton and beans in the second rains. Cotton is the most important crop, and some 160 acres are grown annually for seed multiplication. The farm at Namulonge is divided into a number of farm units following different crop sequences but the units are not independent and they do not allow of separate cost studies. Hence this paper makes use of 'enterprise costings' rather than 'unit farm costings'. The shortcomings of this type of costing are described, though the results are considered to be of value in making tentative assessments of the profit prospects of possible cropping systems. The method and the data presented are considered to be of great importance in a country where farm mechanization is in its infancy, and an essential preliminary to more detailed studies.

Tractor and labour inputs, of which continuous records have been kept since 1956, are presented in full and there are sections on systems of cultivation and crop sequences, market prices, and crop yields. These data have been used to prepare breakeven charts and, from these, net and iso-revenue charts. In general the charts suggest that the highest net returns per acre are to be found with cotton and groundnuts, that growing beans reduces the net income of the system, and that maize is unlikely to make much profit and may make a loss with low prices. A further paper is planned which will set out budget estimates of receipts and expenditures over a period of years and the likely management problems of a mechanized cotton farm.

SOME 160 acres of cotton are grown annually at the Cotton Research Station, Namulonge, Uganda, primarily for the multiplication of seed of improved varieties. Namulonge is in a bimodal rainfall area and there are two cropping seasons each year. Other crops are grown besides cotton, and examples of the rotations followed are given below. The total annual farm production amounts to about 70 bales (400 lb.) of cotton lint; 80–100 tons of maize; 40–50 tons of groundnuts (in pod); and 10–15 tons of beans. At the beginning of the 1956–7 cotton season a farm-costings study was started, and the preliminary results are recorded in this paper.

Namulonge is situated 15 miles north of Kampala. Ecologically it is on the edge of the perennial crop zone where coffee and bananas in particular offer lucrative opportunities for commercial production. In this area, therefore, cotton is seldom seen in plots larger than 1 acre, and Namulonge should be regarded as a specialized cotton-seed farm. Farther to the north, however, conditions become less suitable for perennial crops and here the introduction of large-scale commercial cotton

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farming becomes conceivable. While there are dangers in applying Namulonge experience to these areas, the data recorded here are likely to be of value in making tentative assessments of profit prospects of possible cropping systems.

System of Cultivation and Crop Sequences

The total cultivated area at Namulonge is about 450 acres, of which 300 are down to crops and 150 to *Chloris gayana* ley. Except for harvesting and part of the weeding, all farm operations are fully mechanized. In the main the land slopes fairly steeply, the range being from about 2 to nearly 9 per cent., and tied-ridge cultivation is practised with all crops. On the Nalumuli farm[1] the rotation is as follows:

	1st rains	*2nd rains*
1st year	maize	cotton
2nd year	groundnuts	beans
3rd year	maize	cotton
4th, 5th, and 6th years . .	*Chloris gayana* ley	

On Kirimantungo farm[1] the crop sequence is continued for six years before going down to three years *Chloris* ley. The maize–cotton, groundnuts–beans, crop sequence is especially well suited to a double-cropping régime from the point of view of timing and practicability (see Namulonge Annual Reports).

Tractor Output and Costs

Wheeled tractors are used for all farm operations except disking and heavy ploughing which is done with a crawler tractor. On a large station such as Namulonge, where about 70 acres of ley are ploughed up each year, the crawler tractor is particularly useful for ploughing under dry conditions. The purchase of a crawler tractor for a small farm of, say, 60–100 acres would not be justified and the ploughing of leys would have to be done during the rains. In place of the heavy-type tandem disk drawn by the crawler, a lighter, mounted model could be used repeating the operation twice if the land is rough. Besides the crawler the tractor strength consists of three Fordson Majors and a Ferguson. On the farm the Ferguson is used for rolling and carting only. The main implements in use on the farm are one 'Giantrac' mouldboard plough, one 'Dragoon' disk plough, two 3-furrow mounted disk ploughs, two tandem disk harrows, a disk ridger (three ridges), a four-ridge mounted bobbin roller, a four-row planter, and three trailers. The average number and the range of tractor hours spent on field operations are set out in

[1] The Cotton Research Station, Namulonge, is divided into a number of farm units following different crop sequences. Nalumuli and Kirimantungo are two of these. They are not independent units, however, and they do not allow of separate cost studies. Hence, this paper makes use of quantitative input-output data obtained from these farms to set down 'enterprise costings' rather than 'unit-farm' costings. Lack of knowledge in this field is such that the procedure seems worthwhile at this stage, although it is not considered to be a substitute for a 'forward-budget' analysis which must come later.

Table 1. With groundnuts an additional hour per acre is required for digging. The figures are compiled from automatic Servis recorders which are fitted to all tractors. Taking one idling hour as equal to half a working hour, the average tractor time expended on a full set of cultivations is about 5 hours per acre.

TABLE 1. *Summary of Tractor Performance Experienced at Namulonge*

Operation	*No. of records**	*Range*		*Mean*	
		Working	*Idling*	*Working*	*Idling*
		Hours per acre		*Hours per acre*	
Ploughing . . .	14	1·30–2·00	0·09–0·40	1·57	0·22
Disking . . .	11	0·50–1·23	0·06–0·25	0·81	0·13
Ridging . . .	14	0·40–0·79	0·03–0·37	0·63	0·15
Rolling . . .	10	0·30–0·62	0·05–0·39	0·46	0·17
Planting . . .	15	0·39–0·65	0·06–0·20	0·48	0·11
Inter-row cultivation .	13	0·55–0·82	0·10–0·37	0·69	0·22
Total . . .	77	3·44–6·11	0·39–1·98	4·64	1·00

* Each record is for a field of about 30 acres. Thus for ploughing the average is derived from field experience of about 400 acres of ploughing.

The overall average tractor input per crop on Nalumuli in 1956–7 was 3·7 hours per acre (Table 2). Preplanting cultivations, except for re-ridging, are omitted in the maize–cotton sequences and cotton is sown on the old maize ridges [1]. Thus first-year maize planted on land newly broken from ley takes up 6·4 hours per acre while the input for the following cotton is 1·9 hours per acre only. This low cotton input cannot, however, be obtained without maize, and, for the present purpose, the costs of mechanical cultivation are best shared between these crops. When considering alternative cropping systems this is not satisfactory, and a partial budgeting method must be used. An average input of 5 hours per acre (Table 1) is adopted for the breakeven analysis rather than the lower figure for Nalumuli in 1956–7. If anything, the tractor cost shown on the breakeven charts might be slightly overestimated.

The Uganda Government operates a number of tractors which are hired to private cultivators mainly for ploughing. The total operating cost of these tractors is approximately Shs. 18/- to Shs. 20/- per hour[1] [2]. On an experimental station or an efficient private farm the cost might be lower, perhaps Shs. 10/- to 15/- per hour, but there are very few privately owned tractors on African farms in Uganda. A nominal figure of Shs. 20/- per hour is adopted as a working basis for this paper. Crop transport from the field to the threshing shed is charged at a nominal cost of Shs. 15/- per acre for a medium-size crop (see Appendix, p. 233).

Labour

The monthly wage of porters (i.e. farm labourers) at Namulonge is Shs. 48/- to 52/-, roughly Shs. 1/60 per day. When overhead costs

[1] E.A. Shs. 20/- equals approximately £1 sterling. E.A. Shs. 1/- equals 100 cents.

TABLE 2. *Monthly Distribution of Tractor Hours, 3–3 Rotation, Nalumuli, 1956–7*

Farm size: 180 acres; 90 acres ley, and three 30-acre arable fields

	Maize	*Cotton*	*Ground-nuts*	*Beans*	*Maize*	*Cotton*	*Total*
	Tractor hours per field						
January	72	..	..	..	49	..	121
February	25	..	..	..	..	..	25
March	..	..	87	..	21	..	108
April	19	..	..	..	..	..	19
May	..	..	18	..	..	..	18
June	..	..	32	..	..	36	68
July	..	38	..	60	..	..	98
August	..	..	..	16	..	22	38
September	..	19	..	21	..	..	40
October	..	..	..	..	..	..	0
November	..	..	..	..	..	..	0
December	75	..	..	..	48	..	123
Total	191	57	137	97	118	58	658
Hrs. per acre	6·4	1·9	4·6	3·2	3·9	1·9	3·7

(housing, food, medical attention) are included, the total man-day cost for Namulonge amounts to Shs. 2/80. In addition to porters, prison labour is used for much of the farm work. This labour is charged at the same rate as porters in the breakeven analysis outlined below.

The labour requirements of the four main crops are set out in the Appendix. These are average figures compiled from daily records of starting and finishing times for all hand operations. The groundnut and cotton harvests are expensive in labour, and task work, or payment per lb. picked, is essential to prevent loss of profit at this stage. A fair task for picking groundnuts from the stook is 50–60 lb. per man-day. At Shs. 2/80 a man-day, the cost is thus 5 cts./lb.

In 1956–7 and 1957–8 the peak cotton-picking period at Namulonge fell in January when about two-thirds of the crop was picked [3]. During this time a porter can pick 35–40 lb. a day (7 cts./lb. at Shs. 2/80 a man-day). If an incentive is provided by paying a flat rate per pound picked, some reach as much as 50 lb. per day. At the beginning and end of the season, when there is less cotton on the plant, the picking rate falls to 10–20 lb. (14–28 cts./lb.). The average cost for the season is about 10–15 cts./lb. Picking costs will, of course, vary from place to place and allowance for this has been made in the charts (see Figs. 2 and 3, graphs 6 and 10).

The number of man-days for weeding (about 20 man-days per acre) at Namulonge is high compared with experience at Kigumba in Bunyoro, Western Uganda. For example, the mean figure for weeding maize over three seasons (1952–4) was 6 man-days per acre (E. H. Jones, private communication, 1959). This difference is partly due to the large amount of labour required to prevent the spread of 'lumbugu' (*Digitaria scalarum*), a very serious weed of cultivated land in Buganda. It is a

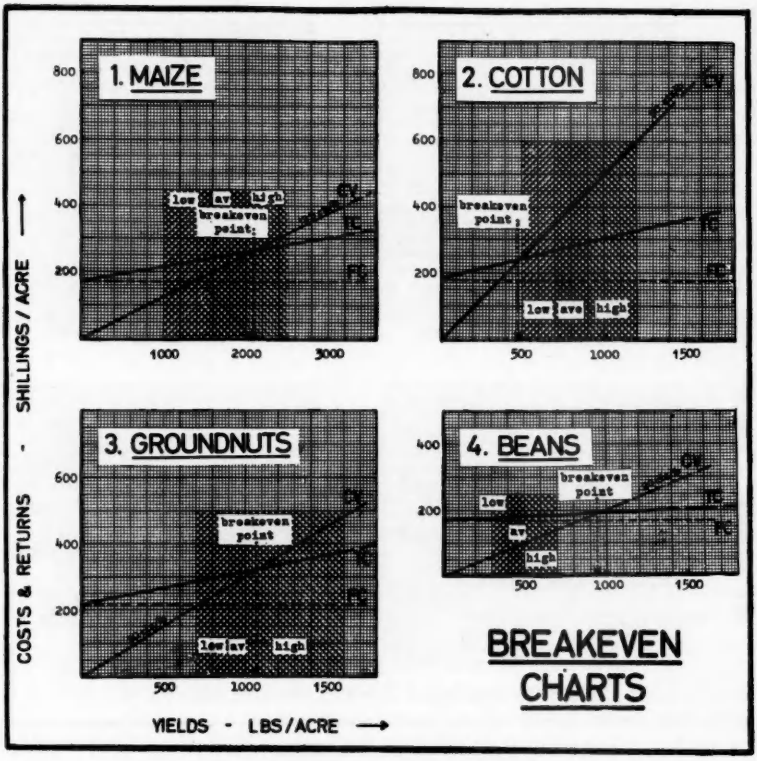

FIG. 1, graphs 1–4. Breakeven charts
The shaded areas indicate the ranges of yields experienced at Namulonge.

rhizomatous perennial grass which spreads rapidly if the initial focus of infestation is not eradicated by digging out the rhizomes. The labour input for this operation is about 170 man-days per acre [4]. Thus if 1 acre is cleared by hand on a farm of 20 acres the overall farm input for this operation alone is a little over 8 man-days per acre. Recently Dalapon has become commercially available in Uganda, and this weedkiller offers an alternative method of control. The cost is about Shs. 172/- per acre [4].

Crop Yields

Crop yields on the farm vary considerably from season to season depending on the rains. As a guide, the range of yields that might be expected on a field scale at Namulonge is given in Table 3.

In order to plant cotton early, a quick-maturing (110–120 days) maize is grown, and the general level of yield is thus lower than that with longer-season varieties.

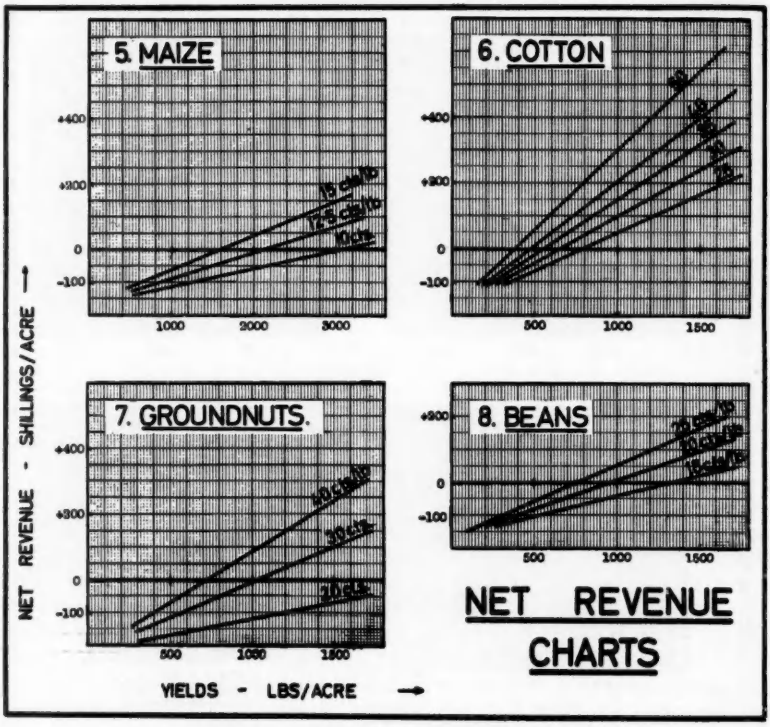

FIG. 2, graphs 5–8. Net-revenue charts

In graph 6 the indicated prices are net of picking costs, i.e. 50 cts./lb. could be a gross price of 60 cts./lb. net of a picking cost of 10 cts./lb. or a price of 65 cts./lb. net of a picking cost of 15 cts./lb. The net-revenue lines plot values of CV–TC (see Breakeven Charts).

TABLE 3. *Crop Yields—Ranges Experienced at Namulonge*

Crop	Yield—lb./acre		
	Low	*Medium*	*High*
Cotton (seed cotton) . .	500–700	700–900	900–1,200
Groundnuts (in shell) . .	700–900	900–1,000	1,000–1,600
Maize (dry grain) . . .	1,000–1,500	1,500–2,000	2,000–2,500
Beans (dry seed) . . .	300–400	400–500	500–700

Crop Prices

The price paid to the grower for seed cotton is fixed annually by the Lint Marketing Board. In 1956–7 the price was 56 cts./lb. It was

58 cts./lb. in 1957–8. This was above the ruling world level, and entailed a subsidy of about 5 cts./lb. from the Price Assistance Fund.

In Uganda there is no official control on the prices of whole maize, groundnuts, and beans, and quotations from buyers on the Kampala market fluctuate considerably. With groundnuts and beans, much depends on the overseas demand, though in general the prices are more stable than for maize. The price of maize is largely determined by the amount of whole maize available for milling in Kampala. If a shortage develops as a result of poor weather conditions, the price may well double itself over 2 to 3 months. Crop storage on the farm and detailed knowledge of the trend of market prices is clearly of great importance. An indication of the range of prices on the Kampala market recently (August 1958) is given in Table 4.

TABLE 4. *Produce Prices for Bulk Sales on the Kampala Market*

Crop	*Price, cts./lb.*		
	Low	*Medium*	*High*
Maize	7·5–12·5 (Shs. 15–25/- per bag)*	12·5–17·5 (Shs. 25–35/- per bag)	17·5–22·5 (Shs. 35–45/- per bag)
Beans	15 (Shs. 30/- per bag)	20 (Shs. 40/- per bag)	25 (Shs. 50/- per bag)
Groundnuts (in shell)	20	30	40

* 1 bag = 200 lb.

Breakeven, Net, and Iso-revenue Charts

In this paper costs and returns will be discussed with the aid of breakeven, net, and iso-revenue charts. While the dangers of placing too heavy a reliance on this method of analysis are specifically noted later, its value in revealing the relative importance of variations in yields, costs, and prices as these affect the prospects of profitability is thought to be considerable. It is hoped particularly that it will appeal to those less familiar with economic analysis.

Breakeven charts for maize, cotton, groundnuts, and beans are shown in Fig. 1. The full data from which these are derived are given in the Appendix. In each of these graphs a diagonal line is drawn through the origin of the axes of the chart. The axes are in each case 'value in shillings' (vertical) and 'yield in pounds per acre' (horizontal). The diagonal lines (CV) allow the value of any weight of crop to be read off on the vertical axis for the selling-price indicated on the line. Thus, in graph 2 1,000 lb. of seed cotton selling at 50 cents per lb. will be worth Shs. 500/- and this can be read off on the vertical axis. The average costs of producing the crop up to harvest are assumed constant and can be shown by a horizontal straight line cutting the vertical axis at the cost per acre (FC). If harvesting costs are assumed to be directly proportional to the weight of the crop harvested, then the total of cultivation plus harvesting costs can be represented by a line cutting the vertical axis at the total cost of the pre-harvest cultivations and rising diagonally to the

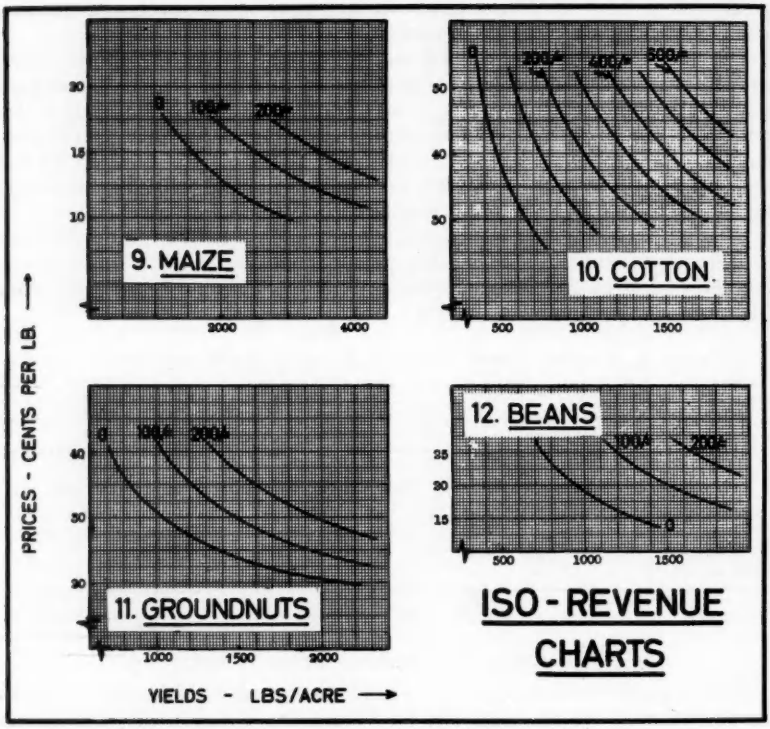

FIG. 3, graphs 9–12. Iso-revenue charts

The figures show the combinations of yields and prices which—with costs at the levels indicated in the text—will produce net revenues of nil, 100/-, 200/-, &c., per acre. For cotton, the price indicated is net of picking costs.

right (TC). At some point the line TC, which represents the total costs of producing any given weight of crop, will cut the other diagonal line CV and at a point immediately below this on the horizontal axis the yield of crop necessary to cover costs (breakeven point) can be read off. Graph 2 shows that the cotton crop will break even at a yield of 475 lb. seed cotton/acre. (Given a price of 50 cts./lb. for seed cotton and a picking cost of 10 cts./lb.)

The vertical interval between CV and TC increases as they move farther to the right and this represents increasing net profits from higher yields per acre (assuming cultivation costs are constant and higher yields due solely to better growing conditions). Net revenue is equal to crop value (CV) minus total cost (TC) or the vertical interval between CV and TC. This can be read off at different yields and for simplicity these readings are incorporated in graphs 5–8 which show net revenues at different yields and with different assumptions of prices and picking costs.

The relative importance of changes in 'fixed' costs (for example, tractor running), variable costs (for example, picking costs), yields, and product prices can be seen on the breakeven charts and on the net revenue charts. It is instructive to 'manipulate' the breakeven charts by redrawing them with other assumptions of costs and prices and so determine, for example, the increase in yield necessary to offset a given rise in picking costs or fall in cotton price. Manipulation of the cost and value lines shows the relative importance of yields, prices, fixed costs, and variable costs as these affect profit margins.

The 'iso-revenue' charts (Fig. 3) indicate the combinations of yield and price necessary to result in the net revenue indicated on each line assuming the costs of cultivation are constant. In graph 9, for example, it will be seen that if maize yields 2,000 lb./acre a price of 13 cts./lb. would be necessary to cover costs.

Yields and Returns, Nalumuli Farm, 1956–7

The yields obtained on Nalumuli farm in 1956–7 were as follows:

Cotton	1,060 lb./acre
Groundnuts	1,360 ,,
Maize	1,500 ,,
Beans	330 ,,

The returns that would result from these net of average production costs can therefore be read off on the breakeven charts as follows:

Crop	*Price, cts./lb.*	*Net return, Shs./acre*
Cotton (picking, 10 cts./lb.)	50	+230
Groundnuts	30	+60
Maize	12·5	−50
Beans	20	−110

Discussion

The Achievement of High Net Returns

Some of the economic aspects of cotton farming at Namulonge have been presented in tabular and graphical form and it is suggested that the breakeven charts and Figs. 2 and 3 help to bring out the relative importance of (i) the price of the product; (ii) cultivation and harvesting costs; and (iii) yields per acre in the achievement of high net returns.

The value of this analysis is not confined to farm-management decisions, it is also of relevance to the selection of research projects in that it allows of a calculation of the probable net benefit of a project which succeeds in increasing the average yields of cotton by a relatively small amount as compared with another project which, for example, might double the average yield of beans. Again, it might help in choosing between spending money on research or extension work to (*a*) increase yields; or (*b*) reduce costs; or (*c*) increase the price paid to the farmer by increasing marketing efficiency or the demand for the product.

One shortcoming of the breakeven analysis is that it does not directly

consider the worthwhileness of incurring increased costs in order to increase yields. The cultivation practices followed are assumed to be the best possible and the yields are assumed to vary with weather, diseases, and pests. Very little is known about the effect of varying costs upon yields. What difference does it make if the number of weedings are increased or decreased, or again if fertilizers are applied? Even in the absence of such knowledge it is necessary to make decisions on these matters and the graphs presented here are of some use in this respect. Those in Fig. 2 are likely to be the most manageable. In these, the effect of cost changes can be seen by re-zeroing the vertical scale. The yield changes necessary to justify these can be read off as the increase in yield which will at least give the same net return. Again, some idea of the extent of cost reductions necessary to make the bean crop break even can be readily gauged from Fig. 2, graph 8. If the average yield is 330 lb./acre and the price is 20 cts./lb. then a cost reduction of Shs. 110/- per acre will be necessary for breakeven (provided that yields are not thereby affected).

The Most Profitable Crops

The figures suggest that the highest net returns per acre are to be found from cotton and groundnuts; that growing beans reduces the net income of the system and that maize is unlikely to make much profit and may easily make a loss with low prices.

These are proper conclusions if:

(*a*) the costs shown are true costs;
(*b*) the revenues shown are true revenues.

The cost picture would be distorted if payments are recorded which would have to be made even if no crop were grown (for example, the tractor driver's wages); or if costs are incurred which are not specifically allocated (for example, overtime rates might need to be paid as a result of a labour peak arising from one crop sequence; averaging labour costs would obscure this). The revenue picture would be distorted if the effects of one crop upon the yield of another were not taken into account.

These considerations are not necessarily revealed by a breakeven analysis which should therefore be used only to stimulate ideas on most profitable crop sequences and to suggest systems which should then be budgeted in cash and labour terms and subjected to other tests of practicability. Nevertheless, the breakeven analysis indicates that it is worthwhile considering whether or not the weight of maize and beans in the present system cannot, with profit, be reduced.

The Relative Profitability of Mechanized Cotton Farming

Ultimately it is necessary to assess the profit prospects of mechanized cotton farming relative to other systems of farming. The above analysis is not appropriate to such an assessment which demands a forward-budgeting analysis comparing the various openings for a man of enterprise and ability who has land and, say, £3,000 (the capital requirements would probably be of this order) and—taking account of risks, labour

problems, marketing problems and the eagerness to see returns—weigh the opportunities that present themselves and so assess the relative attractiveness of cotton farming. A further paper is planned which will set out budget estimates of receipts and expenditures over a period of years and analyse the day-to-day labour and tractor requirements and the likely management problems of a mechanized cotton farm.

Acknowledgement. We are indebted to Mr. H. L. Manning for advice in the preparation of this paper.

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(*Received 8 May 1959*)

APPENDIX

The data used in the breakeven charts, and other diagrams, are set out below. Tractors are charged at Shs. 20/- an hour and labour at Shs. 2/80 a man-day. The fixed average costs, unaffected by the size of the crop, are tabulated first, and this is followed by the variable costs for harvesting, threshing and drying, bags and transport.

MAIZE (Figs. 1, 2, 3, graphs 1, 5, and 9)

Operation	*Input per acre*	*Shs. per acre*
Tractor work	5 hrs.	100·00
Weeding and thinning	23 man-days	64·40
Seed	15 lb.	2·25
Total		166·65

Threshing, drying, and gammexane dusting: Shs. 2/- per 200 lb.
Bags: Shs. 2/- each (200 lb. per bag).
Transport: Shs. 15/- per acre (2,000 lb. per acre).
Harvesting and dehusking: 13 man-days per 2,000 lb. and *pro rata*.

COTTON (Figs. 1, 2, 3, graphs 2, 6, and 10)

Operation	*Input per acre*	*Shs. per acre*
Tractor work	5 hrs.	100·00
Weeding and thinning	23 man-days	64·40
Stalk disposal	6 man-days	16·80
Total		181·20

Picking: 10 cts./lb.
Transport: Shs. 15/- per acre (800 lb. per acre).
Seed is provided free by the Department of Agriculture.

GROUNDNUTS (Figs. 1, 2, 3, graphs 3, 7, and 11)

Operation	*Input per acre*	*Shs. per acre*
Tractor work	5 hrs.	100·00
Weeding	20 man-days	56·00
Digging	1 hr.	20·00
Collecting and stooking	5 man-days	14·00
Seed	60 lb.	30·00
Total		220·00

Picking from stook: 5 cts. per lb.
Bags: Shs. 2/- each (65 lb. per bag).
Transport: Shs. 15/- per acre (900 lb. per acre).

BEANS (Figs. 1, 2, 3, graphs 4, 8, and 12)

Operation	*Input per acre*	*Shs. per acre*
Tractor work	5 hrs.	100·00
Weeding	15 man-days	42·00
Harvesting	6 man-days	16·80
Seed	30 lb.	6·00
Total		164·80

Threshing, drying, and gammexane dusting: Shs. 2/- per 200 lb.
Bags: Shs. 2/- each (200 lb. per bag).
Transport: Shs. 15/- per acre (500 lb. per acre).

FLOWERING AND POLLINATION IN *INDIGOFERA SPICATA*, *PHASEOLUS LATHYROIDES*, *DESMODIUM UNCINATUM*, AND SOME OTHER TROPICAL PASTURE LEGUMES

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Summary

By means of new techniques, flowering, pollination, and pollen-tube development have been investigated in the three important tropical pasture legumes *Phaseolus lathyroides*, *Indigofera spicata*, and *Desmodium uncinatum*. The first two are cleistogamous, whereas *D. uncinatum*, although self-compatible, cross-pollinates to a high degree. *D. sandwicense* has a similar breeding system to *D. uncinatum*. Other species which have been shown to be self-pollinated include *Lotononis bainesii*, *P. atropurpureus*, *Centrosema pubescens*, *Glycine javanica*, and *Stylosanthes gracilis*. The implications of these results to the introduction, seed production, and breeding of these legumes is discussed.

Pollen-tube growth of *I. spicata* and *P. lathyroides* on an artificial medium and on the stigmas of emasculated flowers was governed mainly by relative humidity which needed to be in the vicinity of 95 per cent. for optimum results. Temperature was not so critical, a range between 23° and 30° C. giving the best development. Crosses within *I. spicata* and *P. lathyroides* were obtained only when the humidity around hand-pollinated stigmas was adjusted to a high level. It is suggested that a high relative humidity requirement for pollen-tube growth is a characteristic of cleistogamous legumes whether of tropical or temperate origin.

A RECENT review by Fryxell [1] makes it clear that little on the mode of reproduction in tropical pasture legumes has been published. For a high proportion of those legumes studied by the C.S.I.R.O. Cunningham Laboratory, Brisbane, there was no information on this important aspect. Apart from its bearing on plant-breeding techniques, such knowledge is of importance to the plant explorer as well as being essential when seed production of any species is contemplated. In plant exploring, collection of ecological races would be a major aim in self-pollinated species, while in cross-pollinated species more intensive collections in selected regions would also be necessary to cover the variation available.

The work reported in this paper was done mainly with the species *Indigofera spicata* Forsk.,[1] *Phaseolus lathyroides* L., and *Desmodium uncinatum* (Jacq.) DC. which have shown promise as components of sub-tropical pastures as a result of the work of this laboratory over the last decade [2, 3, 4]. These species are members of the tribes Galegeae, Phaseoleae, and Hedysareae respectively, which contain most of the herbaceous legumes important in the tropics and sub-tropics.

The three species selected for detailed work proved to be self-compatible. However, selfing in the field with porous-type cellophane bags caused considerable abscission of flower-buds. This necessitated a

[1] Previously known as *Indigofera endecaphylla* Jacq.

[Empire Journ. of Exper. Agric., Vol. 28, No. 111, 1960.]

new approach in the investigation of flowering and pollination of these species. Two aspects are covered in this paper. The first concerns time of pollination and pollen-tube growth relative to stage of flower-bud development. The second deals with factors affecting the germination of pollen of *I. spicata* and *P. lathyroides* on an artificial medium and on the stigmas of emasculated flowers.

Materials and Methods

Three strains of *I. spicata* were used. C.P.I. 15362 is a short-day perennial from Ceylon and is densely leaved, pink-stemmed, and stoloniferous. C.P.I. 16110 and C.P.I. 16069 are day-neutral types from North Africa and are annual and biennial respectively with green stems and a non-stoloniferous habit of growth.

The *P. lathyroides* studied was the type naturalized along the Queensland coast, and is day-neutral with a biennial habit. *D. uncinatum* (C.P.I. 8990) was introduced from Brazil and is a short-day perennial with vigorous stoloniferous growth.

For these studies flower racemes were not bagged. All observations were made at the peak of flowering in each species. This was during January and February for the African strains of *I. spicata* and for *P. lathyroides*, and during April and May for *D. uncinatum* and the Ceylon strain of *I. spicata*. Flower buds were classified arbitrarily as non-expanded, expanded, and flowering, and after collection were fixed in ethanol-acetic acid. Non-expanded buds are small and tightly closed, expanded buds are still closed but the corolla is coloured, and in those flowering the standard is separated from the keel. Extent of pollination and pollen-tube growth were determined by dissection under a low-power microscope soon after fixation. Observations before and after fixation showed that a short fixation period removed few if any pollen grains from the stigmas. Cotton-blue in lacto-phenol [5] facilitated the examination of pollen-tube development.

The effect of humidity on pollen germination was studied on an artificial medium. The medium which gave optimum germination at 30° C. was an aqueous one containing 15 per cent. sucrose, 2 per cent. agar, and 0·1 per cent. 'Vegemite', a yeast extract. This medium was smeared at two sites on glass microscope slides and then dusted with pollen. Two glass slides could be held in two parallel slits in the underside of rubber corks which fitted wide-mouthed humidity jars. A range of relative humidities was obtained over saturated salt solutions [6] 0·75 in. deep in jars 4 in. high and 2·5 in. in diameter.

For the studies of pollen-tube growth following artificial pollination of stigmas, racemes with a high proportion of expanded flower buds were selected. The open flowers and seed pods were removed. In the afternoon the remaining expanded buds were emasculated, and the next morning fresh pollen was dusted on the stigmas. The racemes were removed from the plants and the peduncles fixed in the slits of the rubber corks which were then fitted to the jars giving different relative humidities. Shrivelling of the racemes and peduncles did not occur during the test period of 4 hours, even at the lower humidities.

Flowering and Pollination

Indigofera spicata

Flowering in the field was completed by 11.00 a.m. in *I. spicata*, and depending on the strain and activity of bees varying percentages of the flowers 'tripped'. Ten racemes of each strain were tagged and the percentages of newly opened flowers which had 'tripped' by 11.00 a.m. for a 3-day period were C.P.I. 15362: 54·2; C.P.I. 16069: 70·4; and C.P.I. 16110: 14·8. When grown in an insect-free glasshouse flowers of *I. spicata* remained 'untripped'.

Non-expanded flower buds examined in the morning or afternoon contained immature anthers. Expanded buds collected in the afternoon from the three strains contained yellowish but non-dehisced anthers. This was the stage and time when emasculation was most easily accomplished.

In one experiment 100 expanded flower buds were collected at 6.30 a.m. when only an occasional open flower was present, and at 11.00 a.m. on the same morning a similar number of 'untripped' open flowers were collected. Table 1 gives the results obtained from the examination of this material.

TABLE 1. *Pollination and Pollen Germination in Flowers of* I. spicata *at 6.30 a.m. and 11.00 a.m.*

	6.30 a.m. (expanded buds) Percentage of stigmas		*11.00 a.m. ('untripped' open flowers) Percentage of stigmas*	
Strain	*With more than 5 pollen grains*	*With pollen tubes*	*With more than 5 pollen grains*	*With pollen tubes*
15362	51·2	0·0	91·8	46·7
16110	75·1	0·0	83·8	53·8
16069	92·1	0·0	88·9	62·9

In *I. spicata* it was apparent that pollination took place some 4½ hours before the completion of flowering at 11.00 a.m., by which time pollen-tube development was well advanced. *I. spicata* is autogamous and could be classed as cleistogamous in view of the results obtained. This explains the lack of intra-strain variation evident in *I. spicata*.

In this study mode of pollination has not been examined in other members of the tribe Galegeae. It has been studied, however, in *Lotononis bainesii* R.T. Bak., a member of the Genisteae with distinct promise and with a somewhat similar growth habit to *I. spicata*. As in *I. spicata*, anthesis occurred in the expanded but closed flower buds of *L. bainesii* a few hours before flowering. Thus this species is also closely self-pollinated with uniform plant populations.

Phaseolus lathyroides

In *P. lathyroides* 'tripping' did not occur and flowering was usually completed by 11.30 a.m. As in *I. spicata*, non-expanded buds of

P. lathyroides contained immature anthers. The buds most suitable for emasculation were expanded ones present in the afternoon.

On one day during the height of flowering a collection of expanded buds was made at 6.30 a.m. The buds were grouped into three size classes, the mean lengths of the buds within these being 12 mm., 13·5 mm., and 15 mm. respectively. Results from the examination of these buds are summarized in Table 2.

TABLE 2. *Pollination and Pollen Tube Development in Three Sizes of expanded Buds of* P. Lathyroides *collected at 6.30 a.m.*

Number of buds examined	*Mean length of buds mm.*	*% stigmas with pollen grains*	*Mean no. grains per pollinated stigma*	*SE**	*% stigma with pollen tubes*	*Mean no. tubes per stigma with pollen tubes*	*SE**	*Mean length of pollen tubes μ*	*SE**
102	12·0	13·9	28·8	2·19	0·0	..	..	..	..
111	13·5	97·3	64·4	1·08	38·6	4·1	0·40	74	1·98
98	15·0	100·0	72·4	1·60	94·9	6·6	0·50	100	1·86

* SE = standard error of the mean

Depending on the class of expanded bud, pollination, and pollen-tube development was well established by 6.30 a.m. in *P. lathyroides*. Even at 5.00 a.m. anthesis and some pollen-tube development was found in half the buds examined. *P. lathyroides* is thus closely self-pollinated and these results explain the marked uniformity found in this species.

P. atropurpureus DC., a promising perennial species [7], has a similar breeding system to *P. lathyroides*. Other members of the Phaseoleae examined include *Centrosema pubescens* Benth. and *Glycine javanica* L. in which there was no obvious intra-strain variation. In both of these anthesis occurred within the closed keel of the expanded bud before flowering.

Desmodium uncinatum

Experiments with isolated plants have shown that *D. uncinatum* is self-compatible. However, a high degree of cross-pollination is possible as all open flowers 'tripped' either spontaneously or through insect activity and effective pollination did not take place until the flowers 'tripped'. Flowering was usually completed by 11.00 a.m. The amount of cross-pollination which can be expected in *D. uncinatum* was indicated by an experiment with open 'untripped' flowers. The results of this are given in Table 3.

In the flowers 'tripped' in the relatively still air of the laboratory, the percentage of stigmas with pollen grains and the number of pollen grains per stigma were significantly less than in flowers 'tripped' naturally in the field. This experiment suggests that cross-pollination is more important than self-pollination in this species. Only one strain of *D. uncinatum* was available and this showed no obvious intra-strain variation. However, a number of strains of *D. sandwicense* E. Mey have been introduced

TABLE 3. *Effect of 'Tripping' on Pollination in* D. Uncinatum

Treatment	*No. of 'untripped' flowers used*	*Percentage[2] of stigmas with pollen grains*	*Mean no. pollen grains per pollinated stigma*	*SE[3]*
Nil[1]	106	12·3	1·9	0·33
'Tripped' by hand in laboratory .	119	31·1	10·0	0·57
'Tripped' naturally in field .	121	93·4	30·2	0·25

[1] 'Tripped' as soon as placed in ethanol-acetic fixative
[2] Chi^2 [1] = 79·0 ($P<0·001$)
[3] SE = standard error of the mean

and this species has a similar mode of reproduction to *D. uncinatum*. Progenies raised from seed of the different strains of *D. sandwicense* grown in adjacent plots have shown intra-strain variation in stem and flower colour and in the time taken to reach maturity.

Stylosanthes gracilis H.B.K. is another member of the Hedysareae which has been examined. The flowers of this do not 'trip' and the species is autogamous with no intra-strain variation. In the flowers of *S. gracilis* the keel forms a tube which encloses stigma and anthers. At anthesis the stigma is surrounded by the anthers and the stigma then pushes the pollen through the tip of the keel. The stigma then retracts into the keel.

Effect of Relative Humidity and Temperature on Pollen Germination in I. Spicata and P. Lathyroides

It was decided to study the effect of relative humidity and temperature on pollen germination and pollen-tube growth in the two cleistogamous species *I. spicata* and *P. lathyroides*. This was because attempts to make crosses within these species had been unsuccessful.

Pollen Germination on an Artificial Medium

The artificial medium was applied to two sites on each of the glass slides, and fresh pollen of *I. spicata* 15362 and 16110 and *P. lathyroides* was dusted on the treated sites. For each relative humidity level between 31 and 98 per cent. there were two jars, and each jar held two glass slides. The three different pollen samples appeared once in each jar at any one relative humidity level. The jars were held for 4 hours at 28° C. when the slides were removed and cotton blue in lacto-phenol was applied to the treated sites. Two fields at each site were examined under the microscope.

A relative humidity of 95 per cent. or more at 28° C. was necessary for vigorous pollen germination and pollen-tube growth in *I. spicata* and *P. lathyroides*. No pollen germination was obtained on control slides dusted with the different pollens and left exposed on the laboratory bench or in the glasshouse near plants of the two species.

A second experiment was conducted with pollen of *I. spicata* 18557, a similar strain to 15362. This involved fourteen jars, each of which held two slides with four agar-treated sites dusted with pollen. Eleven of the

TABLE 4. *Effect of Relative Humidity on Germination of Pollen of* I. Spicata *and* P. Lathyroides *after 4 hours on an Agar Medium at 28° C.*

	Mean percentage of pollen germinated						*Mean length of pollen tubes μ*					
Relative humidity %	I. spicata 15362	*SE**	I. spicata 16110	*SE**	P. lathyroides	*SE**	I. spicata 15362	*SE**	I. spicata 16110	*SE**	P. lathyroides	*SE**
98·0	65·3	4·15	47·0	0·20	62·1	1·60	244	3·50	213	3·50	238	2·00
95·0	42·0	0	41·3	0·65	32·4	1·20	179	3·50	116	2·00	199	12·00
92·2	2·0	0·25	7·0	1·00	0·0	..	25	5·00	45	5·00	..	..
86·0	1·0	0·50	0·5	0	0·0	..	25	5·25	25	1·00	..	..
80·0 and below	0·0	..	0·0	..	0·0	..	..	..	..	..	..	..

* SE = standard error of the mean

jars were kept at 30° C. for 4 hours and gave a range of relative humidities between 32 and 98 per cent. The other three jars had a relative humidity of 95 per cent. and were held 4 hours at temperatures of 18·3° C., 23·0° C., and 37·8° C. respectively. The slides were removed from the jars at the end of the experiment and the treated sites stained. As before, two fields at each site were examined under the microscope so that each result was determined from eight observations. The results are summarized in Table 5.

TABLE 5. *Effect of Relative Humidity and Temperature on Germination of Pollen of* I. Spicata (*C.P.I. 18557*) *after 4 hours on an Agar Medium*

Relative humidity %	*Temperature ° C.*	*Mean percentage of pollen germinated*	*SE**	*Mean length of pollen tubes μ*	*SE**
98·0	30·0	80·7	0·07	425	18·49
95·0	18·3	53·3	2·77	190	2·65
95·0	23·0	82·9	0·98	590	4·25
95·0	30·0	85·1	0·89	537	2·01
95·0	37·8	62·5	0·61	306	2·19
92·0	30·0	74·7	1·21	334	0·51
86·0	30·0	53·9	0·92	45	1·85
79·5	30·0	4·1	0·68	26	0·17
71·0	30·0	0·0	..	..	..

* SE = standard error of the mean

The trend in these results is similar to that obtained in the previous experiment, although fair pollen germination occurred at a relative humidity of 86 per cent. No pollen germination occurred at 71 per cent. or lower relative humidities. Temperature had a definite effect on pollen germination and pollen-tube growth and temperatures between 23° C. and 30° C. appeared to be close to the optimum.

In order to find the temperature limits for pollen germination of *I. spicata* 18557 a further experiment was conducted in jars with a relative humidity of 95 per cent. and covering a temperature range from 6·1° C. to 43·3° C. The optimum temperature for germination was 30° C. and germination had almost ceased at 15·6° C. and 40° C.

Pollen Germination on Emasculated Stigmas

In May 1956 a further experiment was made with stigmas of *I. spicata* 18557. During the afternoon before the experiment 130 expanded flower buds on a number of racemes were emasculated. Next morning the racemes were removed from the plants after the stigmas had been pollinated with pollen of 18557. The racemes were distributed in jars giving a range of humidities from 32 to 98 per cent. so that there were ten or more stigmas per jar. After 4 hours the racemes were taken from the jars and the pistils removed and stained on glass slides with cotton blue in lacto-phenol.

TABLE 6. *Effect of Relative Humidity on Germination of Pollen on Stigmas of* I. Spicata (*C.P.I. 18557*) *held at 30° C. for 4 hours*

Relative humidity %	*No. stigmas*	*Mean no. pollen grains per stigma*	*SE**	*Mean % pollen grains with tubes*	*SE**	*Mean length of tubes* μ	*SE**
98·0	10	75·6	5·12	61·8	3·18	125	5·38
95·0	10	49·3	7·72	76·6	1·71	131	0·99
92·0	10	13·2	0·77	47·2	1·94	57	2·31
86·0	10	7·0	0·49	0·0	..	..	..
79·5	12	2·1	0·53	0·0	..	..	..
71·0	10	3·0	0·52	0·0	..	..	..
63·5	11	3·0	0·62	0·0	..	..	..
58·0	10	2·6	0·61	0·0	..	..	..
52·0	12	3·8	0·62	0·0	..	..	..
44·0	11	3·1	0·74	0·0	..	..	..
32·0	10	2·7	0·68	0·0	..	..	..

* SE = standard error of the mean

Pollen germination occurred at 92 per cent. relative humidity and above with optimum germination at 95 per cent. relative humidity. Since all the stigmas were hand-pollinated similarly, it is apparent that the number of pollen grains adhering to the stigmas was influenced by the extent to which the relative humidity was above 79·5 per cent. At relative humidities of 79·5 per cent. and below, the numbers of pollen grains adhering were at a similar low level.

Discussion

All the species studied are self-compatible. With the exception of *D. uncinatum* and *D. sandwicense* they can be classed as cleistogamous, if cleistogamy is defined as pollination within the closed bud. This explains

the decided intra-strain uniformity in species such as *P. lathyroides* and *I. spicata*. From the seed-production point of view this is advantageous because the identity of strains can be maintained without isolation in field plots. However, it has meant a more intensive programme of plant introduction in such tropical species in order to obtain a degree of inter-strain variation. There is a distinct need for continuing and vigorous plant exploration in the tropics for further ecological races of promising autogamous legumes. On the other hand, it has been relatively easy to obtain a wide range of variation in the cross-pollinating *D. sandwicense*.

The flowers of *P. lathyroides* do not 'trip', those of *I. spicata* 'trip' only on visitation by bees, while those of *D. uncinatum* invariably 'trip'. In *I. spicata* 'tripping' is unnecessary for pollination, and is thus a vestigial mechanism in this species. The direction of evolution in the breeding habit of *I. spicata* may have been from one of self-incompatibility in which 'tripping' was necessary to the present one of self-compatibility. Lewis [8] maintains that most self-compatible species have been derived from self-incompatible ancestors. It is possible that *D. uncinatum* with its self-compatibility is a stage behind *I. spicata* in the evolution towards a self-pollinating habit.

Tables 1 and 2 show that pollen germinated earlier and more actively on the stigmas of *P. lathyroides* than on those of *I. spicata*. Tables 4, 5, and 6 make it clear that in both these species relative humidity is more critical than temperature for pollen germination on the stigmas. There is little doubt that their cleistogamous habit ensures a high relative humidity within the closed keel at the time of pollination. It would be of interest to measure the relative humidity within the closed keels, but attempts to do this have been unsuccessful. Also it would be of interest to study the effects of relative humidity and temperature on pollen germination in the cross-pollinating *D. uncinatum*. However, it has not been possible as yet to develop an artificial medium on which the pollen of *D. uncinatum* will germinate.

That a relative humidity as high as 95 per cent. is necessary for pollen-tube development in legumes normally grown during summer monsoons could be regarded as axiomatic. However, in Brisbane the relative humidity of the atmosphere varies around 75 per cent. during the growing season. Emasculated buds of both *P. lathyroides* and *I. spicata* failed to develop seeds after pollination, and examination of pollinated stigmas showed that only incipient germination of pollen grains was occurring. Tables 4, 5, and 6 explain this result quite clearly. It was not until the relative humidity was adjusted to a high level around the emasculated and pollinated stigmas that crosses were obtained in *P. lathyroides* and *I. spicata*. It seems that high humidity levels may be needed for pollen-tube development in a number of cleistogamous legumes whether they are tropical or temperate (see Hutton and Peak [9]).

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THE POST-EMERGENCE USE OF HERBICIDES FOR THE CONTROL OF WEEDS IN RICE IN TRINIDAD

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Summary

Of the nineteen species identified in a limited survey of the weeds of swamp rice in Trinidad, *Fimbristylis miliacae* Vahl, *Sphenoclea zeylanica* Gaertn, and *Jussiaea* spp. are recognized as the most important.

From experiments carried out in the greenhouse and in the field, it was shown that *F. miliacae* can be controlled without damage to the rice, by applying ¾ lb. sodium 2,4-D or ¾ lb. MCPA per acre at the time of rapid tillering. It was also demonstrated that *S. zeylanica* can be controlled by applying ¾ lb. ammonium dinoseb per acre, a dose which stimulated the growth of the rice even in the absence of weeds. Finally, it was shown that a mixture of ¾ lb. MCPA with ¾ lb. dinoseb per acre can safely be used at the time of rapid tillering, to obtain simultaneous control of both these weeds. It was also observed that *Jussiaea* spp. were killed by this mixture.

It is recommended that in farmers' transplanted rice ¾ to 1 lb. sodium 2,4-D or sodium MCPA per acre should be used to control *F. miliacae*, but it is suggested that *S. zeylanica* and *Jussiaea* spp. are best removed by hand.

Application of the mixture of ¾ lb. MCPA with ¾ lb. dinoseb per acre is recommended to control all three weed species in directly sown rice, and the use of this mixture has been found essential in experiments with broadcast rice.

A SURVEY of the rice industry in Trinidad [1] showed that of the 736 man-hours required, on average, for the production of an acre of rice, 88 hours are used for the control of weeds by hand. Rice in Trinidad is almost all transplanted, and only swamp-rice is grown, but the control of irrigation water is generally very poor and, as a result, the weed problem is usually severe.

From experiments on the spacing of rice in Trinidad it has been shown that yields can be increased by transplanting closer than usual and it was also concluded that an investigation of the possibilities of using direct seeding was justified [2]. However, one of the main advantages of transplanting rice is the degree of weed control that can be obtained [3], and it was shown that in Trinidad the growth of *Fimbristylis miliacae* Vahl is one of the limiting factors which prevents direct seeding.

The work described in this paper was carried out during the years 1953–8 inclusive, with the object of finding a method of controlling the more important weeds of swamp rice in Trinidad by herbicides, as a cheap substitute for hand weeding in transplanted crops and as an essential prerequisite to further investigations on direct seeding.

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The More Important Weeds of Swamp Rice in Trinidad

In a limited survey of transplanted rice in the vicinity of St. Augustine, the following weeds were found:

Grasses:

Leersia hexandra Sw.
Panicum polygonatum Schrad.
Panicum laxum Sw.
Eragrostis hypnoides (Lam.) B.S.P.
Echinocloa colonum (L.)
Ischaemum rugosum Salisb.
Hymenachne amplexicaulis (Rudge) Nees
Paspalum orbiculatum Poir.

Sedges:

Fimbristylis miliacae Vahl.
Fimbristylis diphylla Vahl.
Cyperus ligularis Boeck.
Cyperus rotundus L.
Cyperus lazulae Rottb.

Others:

Sphenoclea zeylanica Gaertn.
Jussiaea decurrens Walt.
Jussiaea linifolia Vahl.
Commelina elegans Kth.
Pterolepis glomerata Rottb.
Phyla betulaefolia H.B.K.

Of these, *Fimbristylis miliacae* was by far the most common. *Sphenoclea zeylanica* and *Jussiaea* spp. were frequent, and *Leersia hexandra* not infrequent. All other species were rarely found.

During work with directly seeded rice, which has been confined to experimental areas, it has been found that *F. miliacae* and *S. zeylanica* predominate with *Jussiaea* spp. also present but in much smaller numbers. These three species often appear together in directly sown rice.

The Effect upon F. miliacae *and* S. zeylanica *of the Application of Various Chemicals*

After preliminary observation trials ten experiments were carried out to determine the effect upon *F. miliacae* or *S. zeylanica* of the application of the following five chemicals at the doses shown:

Chemicals	*Application rates per acre*
Sodium 2,4-D (2,4-dichlorophenoxyacetic acid)	0·15, 0·30, 0·60, 1·2, 2·4 lb.
Ammonium dinoseb (4,6-dinitro-o-sec-butylphenol)	0·187, 0·375, 0·75, 1·5, 3·0 lb.
CIPC (isopropyl N-(3-chlorophenyl) carbamate)	0·375, 0·75, 1·5, 3·0, and 6·0 lb.
Amino triazole (3-amino-1,2,4-triazole)	1·0, 2·0, 4·0, 8·0, and 16·0 lb.
Sodium 2,4-D mixed with ammonium dinoseb (rate for 2-4D stated first in each pair)	(0·15:0·187), (0·30:0·375), (0·60:0·75), (1·2:1·5), (2·4:3·0)

Each experiment was in randomized blocks with five replications of these treatments and an untreated control. Each plot was 2 ft. square, and was sprayed by timed applications from hand equipment fitted with a pressure gauge. At the time of spraying the plots carrying *F. miliacae* contained plants of mixed ages which had developed during 6 weeks of poor water control immediately after cultivation, and very few weeds of other species were present. The same applied for the plots carrying *S. zeylanica*, which had developed during a period of 8 weeks poor water control. The effect of the sprays was measured by counting plants in the central 18 in. square of each plot before spraying and 10 and 21 days after spraying. The figures for percentage kill, after correction for natural mortality in the controls [4], were transformed into radians [5] before analysis of variance. The results are summarized in Table 1.

The results show that sodium 2,4-D offered the greatest promise for the control of *F. miliacae* while dinoseb was outstanding in its effect upon *S. zeylanica*. The effect of the mixture of 2,4-D with dinoseb was extremely promising, and suggests a means of controlling both weeds with a single application of spray. Amino triazole gave partial control of *S. zeylanica*. C.I.P.C. caused a stimulation of *F. miliacae*.

The Effect upon Rice of Herbicides applied after Emergence

The use of 2,4-D and related compounds for weed control in rice is quite commonplace, especially in the U.S.A., with applications of about 1½ lb. per acre, made at the time of rapid tillering. An experiment was conducted to ascertain whether similar doses could be used in Trinidad.

The Effect of Post-emergence Application of Sodium 2,4-D or Sodium MCPA on Yield of Rice

Treatments with dinoseb were also included in this experiment, which consisted of three replications of twelve treatments in randomized blocks. The 2,4-D and MCPA treatments, and the yields obtained, are shown in Table 2. The results obtained with dinoseb are reported later in this paper.

The sprays were applied to 6-weeks-old rice which had been established by sowing 100 lb. seed per acre in moist soil. Irrigation water was not put into the plots until 3 weeks after emergence. At the time of spraying all plots were heavily infested with *F. miliacae*.

The application at the rate of 0·75 lb. or more sodium 2,4-D or 1·0 lb. or more MCPA per acre, gave complete control of *F. miliacae* and even the rate 0·75 lb. MCPA per acre reduced the weed population to negligible proportions, although the kill was not complete. Only at the rate of 1·5 lb. MCPA per acre were yields significantly higher than on the unweeded plots, but in view of the confirmatory nature of this experiment, the results suffice to show that, in Trinidad, up to 1½ lb. of either sodium 2,4-D or sodium MCPA per acre could safely be applied to rice 6 weeks after planting. ¾ lb. of either material per acre was sufficient to control this weed but sodium MCPA was the safer chemical

TABLE 1. *The Effect upon* Fimbristylis miliacae *and* Sphenoclea zeylanica *of applying Various Chemicals after Emergence*

Dosage of sodium 2,4-D in lb./acre

	0·15	0·30	0·60	1·2	2·4	*Response significant at:*
Percentage kill *F. miliacae*	31%	82%	82%	92%	81%	P = 0·01
Percentage kill* *S. zeylanica*	11%	6%	18%	14%	61%	Not significant

* This species showed distortion, but recovered very rapidly.

Dosage of ammonium dinoseb in lb./acre

	0·187	0·375	0·75	1·5	3·0	*Response significant at:*
Percentage kill *F. miliacae*	4%	¼%	11%	9%	30%	P = 0·05
Percentage kill *S. zeylanica*	1%	66%	87%	100%	100%	P = 0·001

Dosage of CIPC in lb./acre

	0·375	0·75	1·5	3·0	6·0	*Response significant at:*
Increase of *F. miliacae*	3%	36%†	54%†	19%†	8%†	Not calculated
Percentage kill *S. zeylanica*	4%	37%	59%	5%	49%	P = 0·01

N.B. † These values represent increases over unsprayed controls.

Dosage of amino triazole in lb./acre

	1·0	2·0	4·0	8·0	16·0	*Response significant at:*
Percentage kill *F. miliacae*	24%	24%	49%	22%	39%	Not significant
Percentage kill *S. zeylanica*	64%	61%	66%	54%	97%	Not significant

Dosage of sodium 2,4-D mixed with dinoseb (2,4-D above, dinoseb below, in lb./acre)

	0·15 0·187	0·30 0·375	0·60 0·75	1·2 1·5	2·4 3·0	*Response significant at:*
Percentage kill *F. miliacae*	54%	25%	49%	88%	88%	P = 0·05
Percentage kill *S. zeylanica*	85%	73%	97%	100%	100%	P = 0·05

TABLE 2. *The Effect upon the Yield of Directly Seeded Swamp Rice (lb./acre) of applying 2,4-D or MCPA six weeks after Planting*

Treatment	*Yield of unmilled rice (14% moisture)*
Sodium 2,4-D 0·75 lb./acre	1,577
,, ,, 1·5 ,,	1,561
,, ,, 2·25 ,,	1,442
,, MCPA 0·75 ,,	1,609
,, ,, 1·5 ,,	1,938
,, ,, 2·25 ,,	1,672
Control (not weeded)	1,318
Least significant difference between any treatment and control (P = 0·05)	414 lb./acre

to use. These findings are in general agreement with those of other workers [6, 7, 8].

The Effect upon Swamp Rice of Post-emergence Applications of Dinoseb

S. zeylanica, which is not killed by 2,4-D at rates tolerated by rice, is extremely sensitive to small doses of dinoseb. When this work was started, no information on the post-emergence use of dinoseb in rice could be found. In work subsequently published [9] it was discarded as being without value, although detailed reasons for this were not given.

Preliminary work at the Imperial College of Tropical Agriculture, carried out in boxes by Fyfe [10], showed that no plants were killed by applying up to 6·0 lb. ammonium dinoseb per acre 3½ weeks after sowing, and from visual comparisons Fyfe inferred that doses up to 2·0 lb. per acre ultimately stimulated growth although the outer leaves were scorched by the spray. Fyfe's results on the effect of different times of application were, for various reasons, rather unreliable, but tended to show that the chemical was best applied between 3 and 5 weeks after planting. This is in general accord with the view expressed by Blackman, Holly, and Roberts [11] that grasses are most tolerant of dinitrophenols at the time of active tillering.

The effect upon dry weight of rice seedlings. In this experiment doses of dinoseb equivalent to 0·375, 0·75, 1·5, 3·0, 6·0 lb. active ingredient were applied to rice seedlings 5 weeks old, grown in boxes.

Six replications were used in randomized blocks in which a 'plot' consisted of three boxes each 18 × 17 × 4 in. and each containing thirty plants at the time of spraying. After spraying, the boxes were kept upon a concrete floor and surrounded by a small clay bund whereby water was kept about 1 in. below the level of the soil.

The doses at the rates of 6·0 and 3·0 lb. per acre both caused a limited number of deaths and severe scorching of the leaves; smaller doses caused no deaths but leaf scorch and a temporary stunting of the plants which increased in severity with increasing dose.

One week after spraying, and at three subsequent weekly intervals,

samples were taken for determination of the mean dry weights per plant. The results obtained are plotted in Fig. 1 which shows clearly that at the rate of 6·0 lb. per acre dinoseb caused permanent harm. Doses up to the rate of 3·0 lb. per acre caused a temporary setback in the rate of gain of dry weight; this was followed by recovery. There are signs of a small degree of stimulation with the application at the rate of 0·375 lb. per acre. A dose of 3·0 lb. per acre may be marginal.

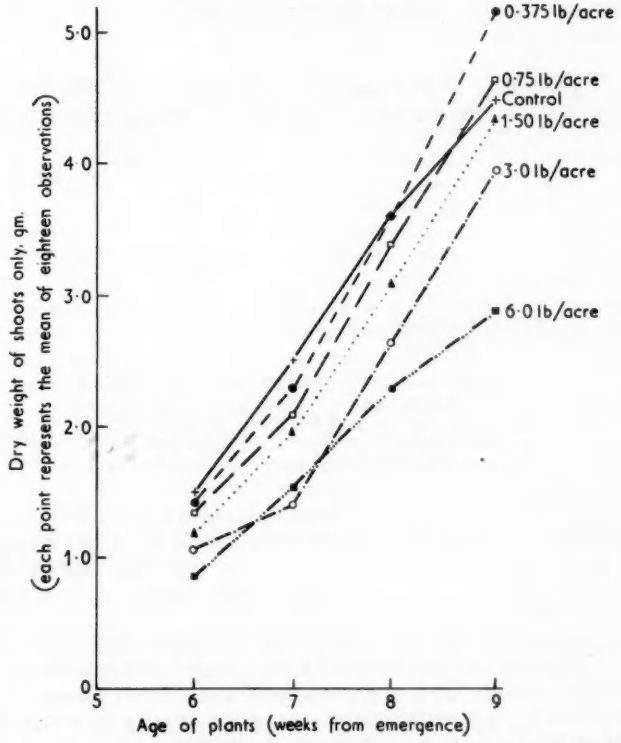

Fig. 1. Effect of dinoseb applied five weeks after emergence, on the dry weight of rice seedlings.

The effect upon tillering of rice. The previous experiment was carried out in boxes 4 in. deep in which restricted 'root-room' severely limited the period for which observations could be made after spraying.

In this experiment the same range of treatments was applied to rice plants 5 weeks old, each of which was grown in a box 10 × 10 × 10 in. A box containing one rice plant was considered as a plot, and eight replications of the six treatments were used. The method of spraying and the manner of storage were as previously described.

Five of the eight plants sprayed at the rate of 6 lb. dinoseb per acre

died shortly after spraying, and six of the plants which received 3 lb. per acre also died. One each of the plants sprayed at the rates of 0·375 and 1·5 lb. per acre died, and all the remaining sprayed plants showed in varying degrees the typical leaf burn caused by the application of dinoseb.

Observations were confined to counting the number of flowering culms produced by each plant. No measurement of yield could be made, largely owing to damage by small birds which passed through the ½ in. wire mesh intended to protect the experiment.

The head counts are summarized in Table 3.

TABLE 3. *The Effect of Post-emergence Applications of Dinoseb upon the Number of Flowering Culms produced by Rice Plants grown in Boxes*

Treatment, lb. dinoseb per acre	*Number of fruiting culms per plant*
0	48·1
0·375	72·5
0·75	65·3
1·5	32·9
3·0	(26·5)
6·0	(6·0)
Least significant difference	25·2

Only the results for the first four concentrations (0–1·5 lb.) were analysed owing to the high degree of mortality at 3·0 and 6·0 lb. The means of the number of fruiting culms of the survivors for the high concentrations have been shown in brackets.

Variations between similarly treated plants were wide and although there was an increase in the number of culms for the applications at the rates of 0·375 and 0·75 lb. per acre, neither was significantly different from the control, although the effect of the former approached very closely to significance.

Applications at the rates of 3 and 6 lb. per acre caused a higher proportion of deaths than in previous and subsequent experiments. This was probably because the lower portions of the isolated plants were more exposed to the spray than where groups of plants were growing together, when the outer leaves provided mutual protection.

The effect upon the yield of rice. In the first of two field experiments the sodium salts of 2,4-D and of MCPA, and the ammonium salt of dinoseb, were all included in a randomized block design, with three replications of a total of twelve treatments. The 2,4-D and MCPA treatments, and the results obtained, have already been reported (pp. 248–9). The dinoseb treatments and the yields obtained are shown in Table 4.

The chemicals were applied to 6-weeks-old rice which was established by sowing 100 lb. of seed per acre in soil. At the time of spraying, the crop was very seriously infested with *F. miliacae*.

The typical symptoms of burn of the outer leaves of the rice were noted 2 days after spraying but, although the damage caused by the

TABLE 4. *The Effect upon the Yield of Directly Seeded Swamp Rice of applying Dinoseb six weeks after Planting. (No susceptible weeds present at the time of spraying)*

Rate of application of dinoseb (lb./acre)	*Yield of unmilled rice in lb./acre (14% moisture)*
Nil (control)	1,318
1·0	1,342
2·0	1,317
3·0	1,326

Differences between treatments not significant.

3·0 lb. dose appeared to be very severe, none of the plants died, and recovery was rapid. The weed plants were very largely protected from the spray by the taller rice plants. Where the spray did contact the weed the leaves showed signs of local damage, but the plants were not killed and did not appear to be suppressed, even temporarily.

This experiment confirmed that dinoseb was completely without value for the control of *F. miliacae*. However, none of the applied doses reduced rice yields and it appears that up to 3·0 lb. dinoseb per acre may be applied to swamp rice without permanently damaging the crop.

In a second field experiment dinoseb was applied to 5-weeks-old, directly sown rice of the varieties Joya (the kind most commonly grown in Trinidad) and Paradijs, an importation from Surinam. The water was removed before spraying and returned to the plots 2 days after spraying. The doses used and the yields obtained are shown in Table 5. The yields shown are means of the two varieties.

The four spray treatments were combined with the two varieties in four replications of the eight possible treatment combinations. At harvest each plot occupied a little over $\frac{1}{100}$th of an acre, after the removal of the guard rows. Very few weeds of any species were present at the time of spraying.

TABLE 5. *The Effect upon the Mean Yield of Two Varieties of Swamp Rice of applying Dinoseb five weeks after Planting. (Few weeds present at time of spraying)*

Rate of application of dinoseb (lb./acre)	*Yield of unmilled rice in lb./acre (14% moisture)*
Nil (control)	2,545
0·75	3,063
1·50	2,709
3·00	2,773

Differences between treatments not significant.

After spraying, typical symptoms of leaf damage of the rice were noted in all sprayed plots. The effect was particularly noticeable 3 days after spraying, and appeared superficially to be very severe especially where 3·0 lb. dinoseb per acre had been applied. However, inspection showed that the damage was largely confined to the blades of the outer leaves,

although the leaf sheaths also suffered minor damage. These damaged leaves gradually died, and new shoots emerged with grew with such vigour that by 4 weeks after spraying it was difficult to tell which plots had been sprayed.

Analysis of yields (after correction to 14 per cent. moisture) showed that the variety Paradijs significantly outyielded Joya ($P = 0.01$), but the response to the application of the dinoseb was not significant. There was no interaction between the varieties and the herbicide treatment. The mean yields associated with the different spray treatments show that there was a tendency for all the doses of dinoseb, but especially at 0·75 lb. per acre, to increase the yield, even in the absence of weeds, and this is of particular interest in view of the stimulation of both growth and tillering previously observed in plants grown in the greenhouse. The result is of practical importance, since *S. zeylanica*, which is not controlled by 2,4-D, is very susceptible to ¾ lb. dinoseb per acre provided that it is applied before the weed is in flower.

The Effect of applying Dinoseb mixed with 2,4-D or MCPA, as a Post-emergence Spray

It has been shown that both *F. miliacae* and *S. zeylanica* can be controlled by mixtures of dinoseb with either 2,4-D or MCPA, and that the crop is tolerant of these chemicals applied separately. There was reason, therefore, to test the effect of such mixtures on the crop.

Effect on the yield of swamp rice of mixtures of dinoseb with 2,4-D or MCPA applied 6 weeks after emergence. In this experiment 0·375 and 0·75 lb. dinoseb per acre were used alone or in mixture with the following:

0·75 lb. sodium 2,4-D per acre	0·75 lb. MCPA per acre.
1·0 lb. " " " "	1·0 lb. " " "

The ten combinations of these treatments, in three randomized blocks, were applied to 6-weeks-old rice of the variety Paradijs which was planted by broadcasting 100 lb. pre-germinated rice per acre into standing water. The spray was applied after removal of the water.

The yields obtained, after correction to 14 per cent. moisture, were analysed as a simple factorial experiment in which the factors were 'doses of dinoseb' and 'doses of translocated herbicide' (i.e. 2,4-D or MCPA). The main effects are summarized in Table 6.

There was no significant response to the dinoseb treatments but the response to the 'translocated herbicides' was just significant at the 5 per cent. level, with MCPA at 1·0 lb. per acre showing to advantage over 2,4-D at the same rate. There were no signs of any interaction between the effects of the two types of herbicide. It has already been shown that the dinoseb up to 3 lb. per acre can be used without lowering the yield and it follows, therefore, that any of the mixtures can be used with safety. However, it also appears that sodium MCPA was a more suitable constituent of the mixture than sodium 2,4-D, and although the evidence to support this is rather limited, this is a reasonable conclusion

TABLE 6. *The Effect upon the Yield of Directly Sown Rice, of Dinoseb mixed with 2,4-D or MCPA. (Few weeds present at time of treatment)*

Main effect of dinoseb		*Main effect of 2,4-D and MCPA*	
Rate of application of dinoseb (lb./acre)	*Yield of unmilled rice (lb./acre) at 14% moisture*	*Rate of application of sodium 2, 4-D or MCPA (lb./acre)*	*Yield of unmilled rice (lb./acre) at 14% moisture*
0·375	3,005	Nil (control)	2,972
0·75	3,169	0·75 2,4-D	3,113
		1·0 ,,	2,848
		0·75 MCPA	3,146
		1·0 ,,	3,359
Difference between treatments not significant		Least significant difference	325

since it is already known that rice is more tolerant of sodium MCPA used alone than it is of sodium 2,4-D used alone.

Conclusions

Although nineteen weed species were identified in the survey mentioned at the beginning of this paper, sixteen are at present of little importance in Trinidad and only *Fimbristylis miliacae* Vahl, *Sphenoclea zeylanica* Gaertn., and *Jussiae* spp. are frequently found in peasant-grown rice.

Farmers' transplanted rice in Trinidad is very commonly infested with *F. miliacae*, which is difficult to remove by hand and which tends to reinfest the land very rapidly in the absence of good water control after weeding. By applying ¾ lb. of sodium 2,4-D or sodium MCPA per acre, but preferably the latter, at the time of rapid tillering, this weed can be controlled more completely and more permanently than by hand weeding, and at lower cost. Since 75 per cent. of the labour used in rice growing in Trinidad is hired, cost is an important factor. On the other hand, *S. zeylanica* and *Jussiae* spp. seldom present a serious problem in transplanted rice, and they can normally be removed quite easily by hand. The use of dinoseb would therefore be difficult to justify in transplanted rice save in exceptional circumstances.

In directly sown rice, however, it has been found that *S. zeylanica* is of equal importance with *F. miliacae* and both commonly appear together at infestation level during the establishment period. Complete control of both weeds can be obtained by the use of a mixture of ¾ lb. MCPA with ¾ lb. dinoseb per acre, applied between 5 and 6 weeks after sowing. In broadcast rice the removal by hand of *F. miliacae* is almost impossible and of *S. zeylanica* extremely difficult.

Few weeds of *Jussiae* spp. were present when these experiments were carried out, but in rice established by broadcasting on mud it has since appeared in large numbers along with *F. miliacae* and *S. zeylanica*. Fortunately, *Jussiae* spp. are also completely controlled by the above combination of MCPA and dinoseb, and the use of this mixture has already proved to be essential in experiments in broadcast rice.

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NOTE ON RECOMMENDED LISTS OF CEREAL VARIETIES

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THE choice of varieties within the main agricultural crops is sufficiently wide to be bewildering to the practical farmer who has to select but one or two of each crop to grow in any season. New varieties of cereals for trial in England have, for example, been coming forward since the war at the rate of fifty a year.

These varieties are included in replicated variety trials for several years at a range of centres representative of the main conditions in this country. Records are taken of yield, straw characters, maturity, disease, and other points of agronomic importance. For diseases such as loose smut and yellow rust all varieties are subjected to inoculation tests with the several races they are likely to encounter in the field. Grain samples are sent for quality tests by consumer organizations such as the Research Association of British and Irish Flour-Millers, and the Brewing Industry Research Foundation. The aim is to obtain information in this way on all the varieties likely to be suitable for British conditions or which have been offered on the British market. The results of these trials and tests are submitted to an Advisory Committee representative of the farmers, users, and technical authorities, and lists of Recommended Varieties have been issued by the Institute. No variety is recommended on less than three years' results.

Since the early 1930's the National Institute of Agricultural Botany (N.I.A.B.) at Cambridge has been issuing Farmers' Leaflets to help the farmer in his choice of cereal varieties. In the 1940's these leaflets incorporated a statement that certain varieties were 'recommended', and in more recent years the Institute's Recommended Lists have been placed on a more formal basis.

In some European countries the farmer's choice of varieties is restricted by statutory requirements that only certain varieties approved by the national testing organization may be sold. Although it has occasionally been suggested that similar measures should be introduced here, it has been preferred to rely on the advisory services to encourage the farmer to make use of the better varieties which become available, and to leave him free to grow any variety he likes. In special cases there may well be good reasons for growing some particular variety which may not be of general suitability.

Recent discussions on possible amendments to the Seeds Act make it timely to consider how far the farmer has been influenced by the advice available and by the Recommended Lists of the N.I.A.B. It is not easy to obtain precise information on the true popularity of varieties. In recent years surveys have been undertaken by the advisory officers,

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sampling farms in certain areas of the country. These surveys, however, are all quite recent and in any case cover only a small proportion of the English counties.

One source of information is provided by the statistics of the named varieties submitted for germination and purity tests to the Official Seed-Testing Station for England and Wales. The Chief Officers of the Station have published [1, 2] summaries of the figures and discussed their interpretation. Wellington [2] points out that the figures are on a national basis and cannot reflect the strong local preferences which undoubtedly exist. He suggests too that the figures tend to exaggerate the popularity of a variety in the earlier years of distribution and that the numbers of samples reaching his Station are swollen when special demands occur for tests on particular varieties, as in the case of Cappelle Desprez wheat for export in 1957. Despite these qualifications, however, these statistics probably represent the best available indication of the general popularity of varieties over England and Wales as a whole.

The three charts (Figs. 1, 2, 3) present the figures in graphical form. In each case the main central block represents the recommended varieties: the blocks above the top line indicate those which are still being grown although the Institute's recommendation has been withdrawn; and those hanging from the lower line indicate varieties which have become fairly widely grown before formal recommendation. At the foot of each chart are certain varieties which have never been recommended.

The charts are prepared from information on varieties reaching the Seed-Testing Station in any year and include details only for those which form more than 1 per cent. of the total named samples. Varieties, each representing less than 1 per cent., together make up from 5 to 10 per cent. of the total samples each year and are not shown on the charts. They include, of course, a number of the less popular recommended varieties as well as some non-recommended varieties.

The first main conclusion from all three charts is that recommended varieties have formed at least 60 per cent. of the total in every year since 1942. In no crop have varieties never recommended by the Institute exceeded 10 per cent. In the early war years this might have been partly due to a tendency by the Institute in the absence of adequate trials data about them to recommend varieties because they were widely grown. That criticism could not be levelled against the Institute in recent years, and in wheats and barleys over 75 per cent. of the seed samples are made up of varieties recommended for the first time after 1950.

The difference between the general form of the chart for oats and of those for the other two crops is of interest. The changes in oat varieties have been less rapid. Seventeen per cent. of the samples are still old pre-war varieties which are no longer recommended. This no doubt reflects the much wider distribution of the oat crop among the smaller farmers, many of whom are less easily influenced by the advisory services. The Institute was fairly drastic in removing a number of the older and very well-established varieties from the spring oat list in 1954

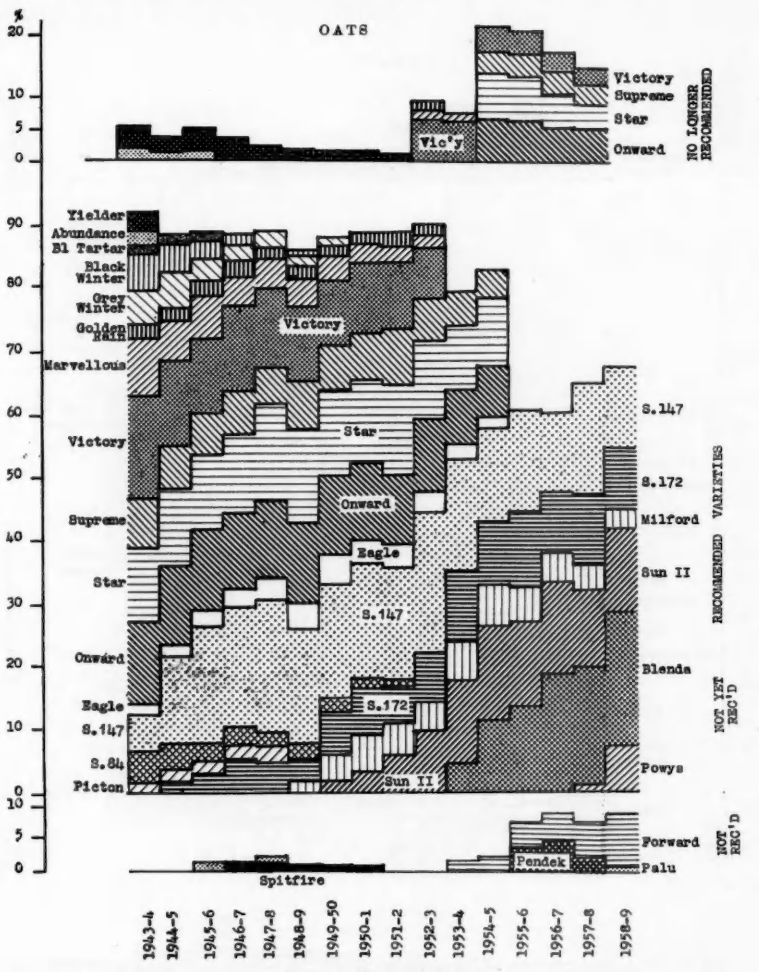

FIG. 1. Oat varieties

Each variety as a percentage of all the named varieties submitted to the Official Seed-Testing Station for England and Wales (varieties each less than 1 per cent. omitted).

and 1955. The four varieties, Onward, Star, Supreme, and Victory had represented 45 per cent. of the total in 1953: this figure has been falling steadily year by year, to 17 per cent. in 1958. Recent trials have confirmed that the farmers who still grow them are losing 10 to 15 per cent. in yield of grain.

Among the wheats, Atle is the only pre-1950 variety which still represents more than 3 per cent. It is noticeable how the large number

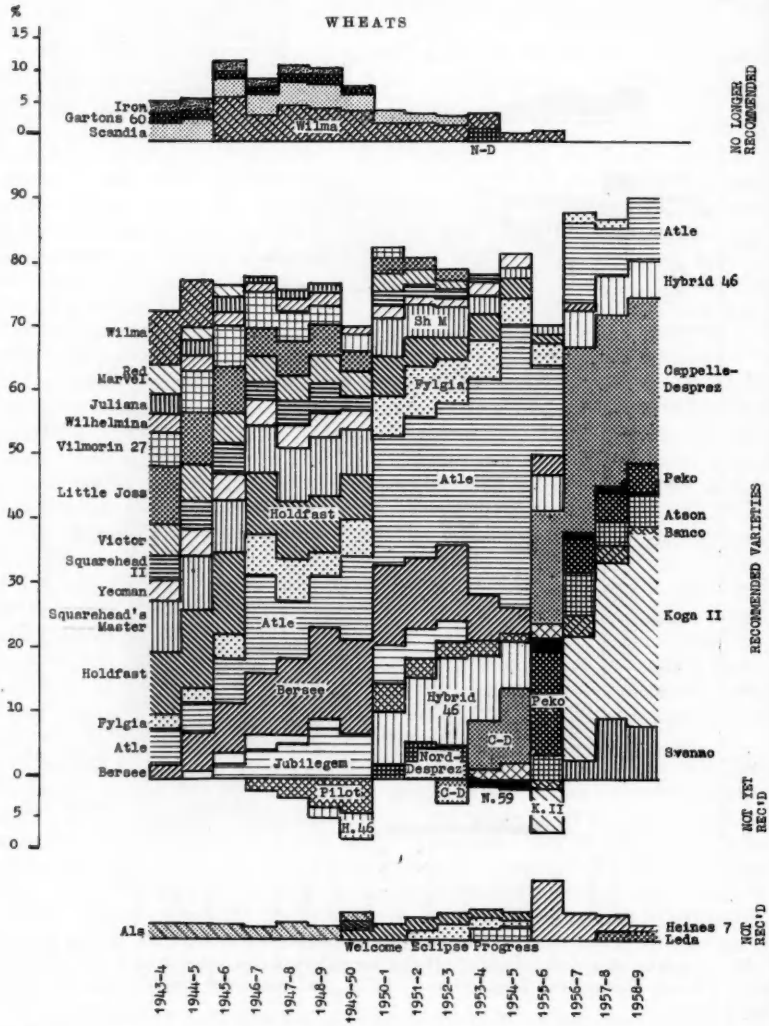

FIG. 2. Wheat varieties

Each variety as a percentage of all the named varieties submitted to the Official Seed-Testing Station for England and Wales (varieties each less than 1 per cent. omitted).

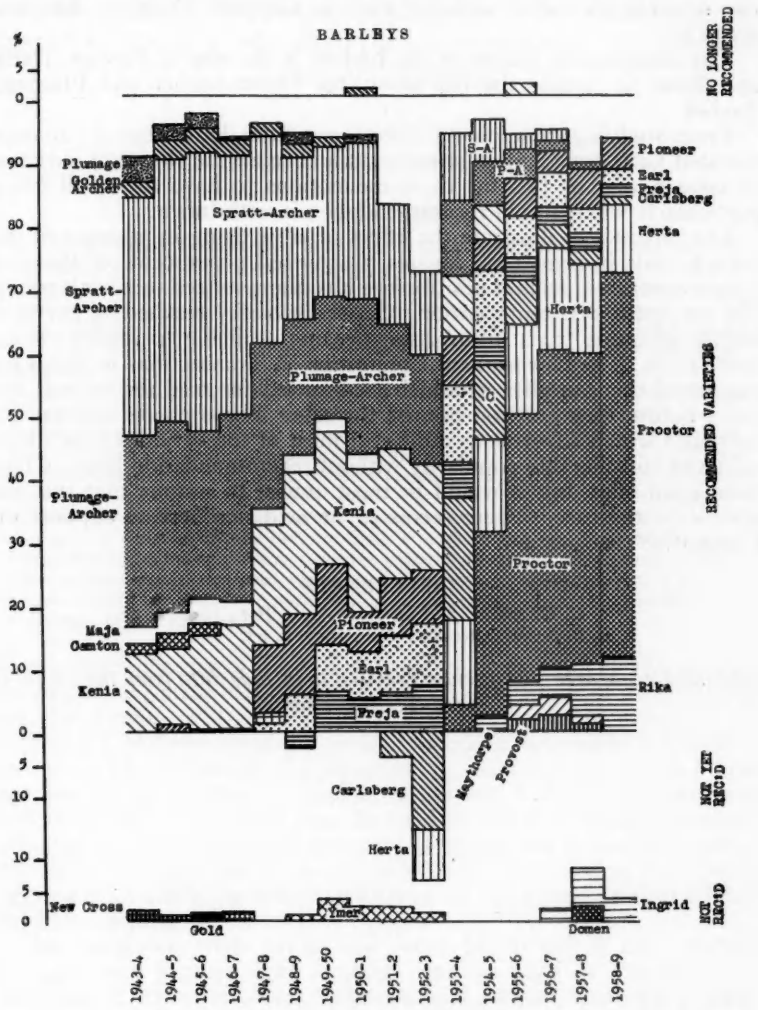

FIG. 3. Barley varieties 1945–58

Each variety as a percentage of all the named varieties submitted to the Official Seed-Testing Station for England and Wales (varieties each less than 1 per cent. omitted).

of varieties, each being used in relatively small amounts, which characterized the war years, has now been replaced by the preponderance of two or three successful varieties such as Cappelle-Desprez, Atle, and Koga II.

The conspicuous feature of the barleys is the rise of Proctor, Herta, and Rika, to replace the old favourites Spratt-Archer and Plumage-Archer.

From studying these charts there seems little doubt that the Recommended Lists have had an effective influence on the choice of varieties. It takes a year or two for recommendations to have their full effect, particularly when an old recommendation is withdrawn.

The charts also illustrate the effect of advertising in advance of impartial trials information. Heines 7 achieved 9 per cent. of the total wheat varieties in its first year, before it was announced that trials results did not justify recommendation. Carlsberg barley reached 15 per cent. before adequate trials information became available to justify recommendation. The Government Committee on Transactions in Seeds has suggested that varieties should be submitted for trial for at least two years before they are first offered for sale. These charts indicate the influence which advertising can have: most of the varieties which have achieved considerable popularity without recommendation have, in fact, been good ones, but it would be most unwise to assume that this will always be the case. There seems to be evidence here to support the Committee's suggestion.

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OBSERVATIONS ON VIRUS DISEASES OF CASSAVA IN RESISTANT AND SUSCEPTIBLE VARIETIES. II. BROWN STREAK DISEASE

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Summary

It was previously thought that low temperatures were inimical to the survival of plants infected with brown streak virus, but when diseased material was grown at high altitudes in Tanganyika it was found that the low temperatures encountered did not induce lethal symptoms. Similarly in trials carried out in coastal regions it was found that temperature, although important, was not necessarily the main factor controlling the intensity of the brown streak symptoms recorded.

An account is given of some variations in the form of brown streak disease which occurred in resistant and susceptible varieties of cassava under test in field-resistance trials. Resistant varieties exposed to infection tended to remain free of symptoms, and when symptoms did occur they were usually mild and frequently restricted to the roots. In these varieties symptoms were often transient, recovery occurring in the second season's growth; but hybrids derived from *Manihot melanobasis* were anomalous in this respect. In an experiment with two susceptible varieties, plants derived from a stock which had been infected for some time appeared to possess a greater capacity to recover than plants derived from a clean stock. Seasonal variations in the severity of brown streak disease in two control varieties were positively correlated with variations in the degree of resistance shown to mosaic disease.

BROWN streak disease of cassava is a serious problem in all the cassava-growing areas on the east coast of Africa. A description of its symptoms and distribution, and of the effects of climate upon it, was given by Nichols [1], and reports of the work of breeding for resistance to it have been given by Nichols [2] and Jennings [3]. In the course of this breeding work a large number of seedling clones were tested for resistance in field trials, and information was obtained on some of the factors which influence the expression and intensity of symptoms in a wide range of hybrids. This information is presented and discussed in this paper, together with some further observations on the effects of cool climate upon the disease.

The resistance trials mentioned were conducted at two centres, Mlingano and Kizugu, both situated near the coast of Tanganyika at about 600 ft. above sea-level. The material studied consisted of back-crosses to cassava (*Manihot esculenta*) of interspecific hybrids between cassava and *M. glaziovii* (Ceara rubber), *M. dichotoma*, *M. catingae*, and *M. melanobasis*. Intervarietal cassava hybrids and named native varieties were also studied. The material was raised and maintained in isolation plots at Amani, situated at 3,000 ft. above sea-level in the Usambara Mountains; this minimized the chances of the plants becoming diseased

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before cuttings from them were exposed to infection in resistance trials. A full account of these trials is given in an earlier paper [3]. Symptoms of brown streak were recorded in leaf, stem, and root: the necrotic stem symptoms were scored for severity after paring away a thin layer of tissue from the abscission layers remaining after normal leaf-fall, and root symptoms were scored in the same way after slicing up the tuberous root. The symptoms varied in intensity: sometimes they involved the whole of the starch-storing tissues of the stem and root, but in resistant varieties, and in susceptible varieties growing under conditions unfavourable to the disease, they usually took the form of occasional necrotic flecks. Symptoms were recorded as absent, mild (Score 1), intermediate (Score 2), or severe (Score 3), and the total of the scores obtained for all the plants of a variety was expressed as a percentage of the maximum possible. The percentage resistance was obtained by subtracting this figure from 100.

The Distribution of the Disease

Nichols [1], who was unable to find diseased plants at altitudes over 3,500 ft., suggested that the low temperatures encountered at such heights were inimical to the survival of diseased plants, so that a 'natural control' operated against the disease. The critical altitude above which all diseased plants were expected to die was tentatively estimated to lie between 3,500 and 4,500 ft. Nichols also thought that there was no spread of the disease by the insect vector at these altitudes.

An opportunity to gain further information on these points occurred when cassava cuttings believed to be infected with brown streak were distributed from Morogoro, in the Eastern Province of Tanganyika, to inland centres in the Central and Southern Highlands Provinces. The cuttings were distributed in 1951 and later years, and plots containing plants derived from them were examined in June 1956. A plot at Igumbiro, near Iringa (5,300 ft. above sea-level) in the Southern Highlands Province, was revisited in April 1957, in order to examine the roots. The results from this plot are summarized in Table 1.

The climate at Iringa is distinctly cool at some periods of the year (the mean minimum temperature is 56·6° F. and the lowest minimum recorded is 41·8° F.). However, the cassava at this site had made particularly good growth, the establishment from cuttings had also been good, and brown streak symptoms even in highly susceptible varieties were only mild or moderately severe. Although leaf symptoms were common in three of the varieties, symptoms in the stem were difficult to find; when present they were less severe than those recorded for the same varieties at Mlingano or Kizugu. Symptoms were mostly confined to the roots.

In the Central Province, plants were examined for leaf and stem symptoms at sites near Dodoma (3,700 ft.), Singida (4,915 ft.), Kolo (4,900 ft.), and Kondoa (4,547 ft.). They had suffered badly from difficult growing conditions, and were severely affected by mosaic disease: certain diagnosis of brown streak in the leaf was not possible, but no stem symptoms were found in a large number of plants examined.

An exception occurred at a site near Kondoa where the plants were much more vigorous: leaf and stem symptoms both occurred, but they were very mild.

The evidence from these two inland Provinces of Tanganyika does not support the hypothesis that natural control against brown streak at high altitudes is due to the lethal effect of low temperatures. At Iringa the presence of symptom-free plants of very susceptible varieties growing

TABLE 1. *Brown Streak Symptoms Recorded in a Trial near Iringa*

Variety	*No. of plants established out of 132*	*No. of plants with symptoms in*			*Mean intensity of symptoms in diseased roots (max. = 3·0)*
		Leaf or stem only	*Leaf or stem plus roots*	*Root only*	
Aipin Valenca	121	0	1	97	1·8
Ankrah . .	118	0	1	71	1·8
Kru . .	88	0	4	9	1·5
Binti Minsi .	94	0	1	46	1·4
Msitu . .	95	4	24	13	1·8
37244E . .	90	0	2	52	1·8
405/1 . .	80	17	63	0	1·8
4023/3 . .	76	0	1	50	1·6
4026/16 . .	68	0	68	0	2·8
4026/20 . .	80	0	3	47	1·7
4029/10 . .	110	1	0	7	1·0
4029/11 . .	106	0	5	37	1·4

alongside diseased plants suggested that the original consignment of cuttings was not uniformly infected. Since the same varieties rapidly succumbed when grown under similar conditions on the coast, the failure of the disease to spread at Iringa supports Nichols's observation that dissemination of the disease does not occur in such locations.

Nichols also quoted a report that brown streak had become endemic in Uganda following the importation in 1934 of diseased stocks from Amani. There was very little spread of the disease, however, and according to the latest report from the Senior Botanist, Mr. D. G. Thomas, there have been no reports of it since 1949. Roguing operations undoubtedly reduced the incidence of the disease but, as at Iringa, there was an unexplained failure to spread.

The Influence of Seasonal Temperature Variation in Coastal Areas

Storey [4] recorded that symptom intensities became greatly augmented at Amani in the cool season (June–October), and for this reason, the recording of brown streak in resistance trials was always done at that time. These trials were planted during the short rains (October–November), with the result that the plants made rapid growth and reached full size during the hot season. Growth then slowed down and the plants eventually became dormant during the cool season. Thus the greater intensity of brown streak symptoms found in July was possibly due not only to the effect of the lower temperatures encountered but also to the indirect effect of the different growth rate of the host.

Evidence to support this hypothesis was obtained in 1956 when a small trial was planted at Kizugu during the long rains (late March) instead of the short rains. In this trial the plants made poor growth for the first two months; during this time insect vectors were numerous and very severe brown streak symptoms appeared in the new leaves at an exceptionally early stage. Temperatures fell in June, but the growth of the young plants improved and it was noticed that in a high proportion of cases the new growth was free of symptoms, which became confined to the lower leaves. Symptom-free growth continued throughout the cool season, and when the plants were examined in September only sixty of the eighty-seven plants recorded as diseased in July showed leaf symptoms. The apparent recovery of the remainder was due to the natural shedding of the lowermost symptom-bearing leaves.

Symptom Expression in Resistant and Susceptible Varieties

The most important factor influencing the intensity of symptoms is the inherent resistance of the variety concerned. For the purpose of this paper, varieties are described as resistant if they tend to remain free of symptoms when exposed to infection. Moderately resistant varieties, which only succumb in a small proportion of plants, tend to produce mild symptoms. The coefficient of correlation between the numbers of plants showing symptoms and the mean intensity of root and stem symptoms was calculated for the varieties in four resistance trials, and found to be highly significant in each case (mean $r = 0{\cdot}75$). It is also apparent that symptoms in resistant varieties are more frequently localized in their distribution. For plants in their first season, localization of symptoms in the roots occurred in about three-quarters of the cases where all parts of the plant were not affected. Thus a common form of the disease in highly resistant varieties is mild brown streaks in the roots, but symptom-free stems and leaves. Alternatively, necrotic lesions at a few nodes of the stem may develop at first, but these may be occluded later when new healthy growth replaces the dead tissue, which sometimes remains visible as a thin layer pushed against the bark.

The localization of brown streak symptoms in the roots was even more common in trials where the plants were harvested in their second season. A comparison of the symptom distribution in the second season's growth of resistant and susceptible varieties is given in Table 2.

The absence of symptoms in the stems in the second season is explained by the fact that they were frequently transient. There is also evidence that the roots can recover from symptoms. Table 3 gives the intensities of brown streak recorded in a trial in which roots of six varieties were examined at three dates subsequent to planting. The trial was planted at Kizugu in October 1954. Hybrid nos. 46106/27 and 4763/16 are derivatives of *M. glaziovii* and hybrid no. 50611/18 is derived from *M. melanobasis*.

The mean symptom intensity recorded at the 15-month harvest was significantly greater than that at 10 months, but the intensity recorded at 20 months was a significant reduction. In the case of the susceptible varieties this may have been due to badly affected roots rotting away

and being lost. However, this has never been observed for the more resistant varieties 46106/27 and 4763/16, which also showed a reduction in symptoms at the last recording. It is interesting to note that the mean yields recorded on the three harvest dates were 15·1, 19·1, and 37·8 kg. per plot respectively: the intensity of root symptoms thus increased

TABLE 2. *The Distribution of Brown Streak Symptoms in the Second Season's Growth of Varieties Tested in Two Resistance Trials (fifteen plants per variety)*

Resistance group	*No. of varieties*	*Percentage of symptom-free plants*	*Percentage of plants with symptoms in*		
			Root only	*Stem only*	*Root and stem*
Highly resistant	16	74·6	13·4	3·5	8·5
Moderately resistant	8	33·3	47·4	2·6	16·7
Slightly resistant	29	7·7	29·4	9·9	53·0
Fully susceptible	5	0	1·3	0	98·7

TABLE 3. *Mean Brown Streak Root Intensity* per Plot at Three Dates of Harvest*

Variety	*Mean intensity per plot at*		
	10 months (22 Aug. '55)	*15 months (30 Jan. '56)*	*20 months (3 June '56)*
Mbarika .	9·3	14·7	8·7
A. Valenca .	5·3	10·0	7·0
50611/18 .	2·3	7·0	11·0
46106/27 .	1·3	3·0	0·0
4763/16 .	0·3	6·3	2·3
Mean . .	3·7	8·1	5·8

* Maximum intensity per plot is 18.

Least significant differences ($P = 0·05$); treatments = 4·1; times of harvest = 1·8.

during a period when little root growth was taking place, and decreased when growth was active.

The variety × time interaction for root symptom intensities in this experiment was also significant. It was noted that the behaviour of the *M. melanobasis* hybrid (no. 50611/18) during the last growth period was different from the others: symptoms were either extremely severe or absent altogether. This suggested that plants which successfully resisted infection in the early stages of the trial were still healthy at the end, whereas the intensity of symptoms had increased in those which were infected early. Hybrids derived from *M. melanobasis* were among the most resistant available, if their resistance was assessed from trials of one year's duration; but their behaviour was anomalous in the second

season, when the whole of the tuberous roots of infected plants might become necrotic. Similarly, stem symptoms in these hybrids either increased or were only rarely displaced in the second season. This was demonstrated in a trial where stem symptoms were scored in October (12 months after planting) and again in the following January. The second recording followed a period of rapid growth which enabled the plants to recover to some degree: compared with the other hybrids in the trial, the *M. melanobasis* hybrids showed a reduced tendency towards recovery, the total scores at the second recording being 89 per cent. of the first, while the proportion was only 64 per cent. for the other hybrids.

The Influence on Symptom Expression of the Health of the Parent Material

An experiment[1] was planted in September 1949 to compare the yields and symptom intensities of two susceptible varieties, Msitu and 4332/2,

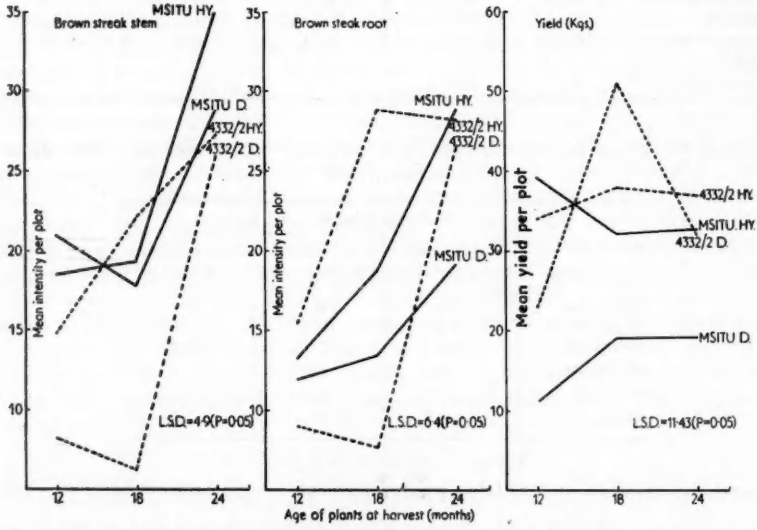

FIG. 1. Comparison of symptom intensities and yield at three dates of harvest for healthy (HY) and diseased (D) stocks of Msitu and 4332/2 (*M. glaziovii* hybrid).

at three harvest dates, when cuttings were taken from healthy stocks, and from stocks which were infected with both mosaic and brown streak viruses. The design was such that the spread of both diseases within the trial was rapid. The results given in Fig. 1 show that in 4332/2 the intensity of brown streak symptoms both in the stem and root was significantly greater in the plants derived from the healthy stocks: this was particularly true at the 18-month recording which followed a period

[1] This experiment was done by Mr. R. F. W. Nichols before his accidental death in 1951.

of active growth. Symptoms were severe in all the stocks at the final harvest. Since the yield of root at this harvest was less than at the previous one, it is probable that the increase in symptom intensity is attributable to the fact that active growth had ceased. The lower yields of the diseased stocks were, of course, due to the combined effects of both viruses. The reason for the relatively low symptom intensities recorded in the plants derived from diseased cuttings is obscure. One possible explanation is that infected stocks can acquire a tolerance to the virus after a period of time: if this is so, tolerance was apparent in the present case only when the plants were growing actively.

No further experiments of this kind were done to confirm this result. In an experiment where cuttings from very severely affected plants were used there was no indication of an acquired tolerance, but results suggesting such a tolerance were obtained again from the 1954 trials. For these trials, instead of the usual practice of planting healthy cuttings from isolation plots, material which had been exposed to infection in an earlier trial was used. The plants from which cuttings were taken were first scored for brown streak symptoms in August 1953; the resulting plants, twelve per variety, made very good growth and were scored for disease symptoms when the trial was harvested 10 months later.

The intensity of brown streak found in plants derived from cuttings taken from plants showing the maximum intensity was surprisingly low. It appeared that environmental factors, or possibly an increase in tolerance acquired by the infected stocks, played such a large part that the disease status of the planting material was not the most important factor governing the disease in the trials. The results are given in Table 4.

TABLE 4. *A Comparison of Brown Streak Intensity in the Parent Material and the Resulting Plants at 10 months*

	Mean intensity of stem symptoms (max. = 100)	
No. of varieties	*In planting material*	*In 10-month-old plants*
106	100	50
55	67	33
56	33	24
261	0	15

Correlation Between the Expression of Resistance to Mosaic and Brown Streak Viruses

The virulence of brown streak disease in the control varieties which were included in short-term field trials conducted from 1941 to 1953 varied considerably with seasonal and other factors. Mosaic disease also varied in virulence and tended to be virulent in those trials in which brown streak was also virulent. Thus recorded variations in the degrees of resistance to the two viruses were correlated. The relationship is shown in Fig. 2. All the plants were infected with mosaic disease but resistance was calculated by expressing the symptom-free period as a

percentage of the total period [2]; resistance to brown streak is the mean of that recorded for stem and root.

The effects of different climates on the severity of the two diseases also appear to be similar. Just as varieties maintained a greater level of resistance to mosaic disease in inland areas of East Africa than on the coast [3], the brown streak symptoms recorded near Iringa and Kondoa were less severe than those usually recorded in the same varieties in the coastal areas.

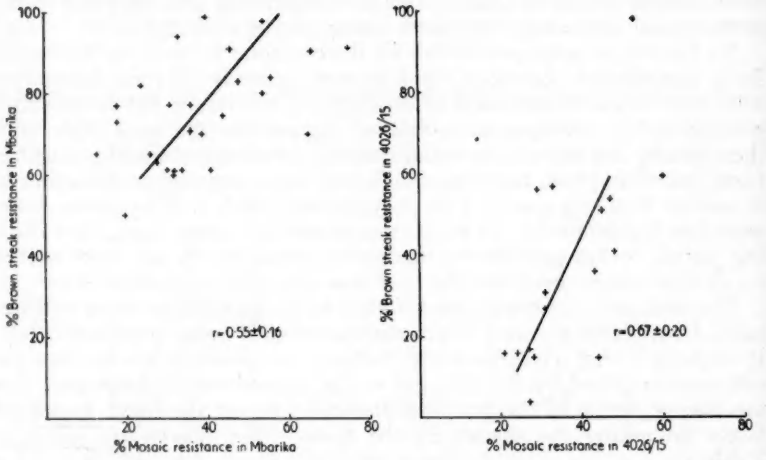
% Brown streak resistance in Mbarika
% Mosaic resistance in Mbarika
r=0·55±0·16
% Brown streak resistance in 4026/15
% Mosaic resistance in 4026/15
r=0·67±0·20

FIG. 2. The relationship between the expression of mosaic resistance and that of brown streak

Discussion and Conclusions

The mode of spread of brown streak disease in the field has not been determined with certainty. Storey [5] obtained evidence suggesting that a white fly (*Bemisia* spp.) was the vector responsible, but this result has never been confirmed. More recently Lister [6] has shown that the virus can be transmitted mechanically. An important question from the point of view of this paper is whether infection occurs through the leaves or whether the virus is transmitted through the soil. If infection occurs through the leaves, it would appear that in resistant varieties the virus frequently moves to the root without inducing symptoms in the stem or leaves. Alternatively, but with the exception of hybrids derived from *M. melanobasis*, the virus may cause transient symptoms to appear in the aerial parts, the second season's growth being symptom-free. On the other hand, if the virus is transmitted through the soil, it would seem that in resistant varieties it does not always move upwards to induce symptoms in the aerial parts. In these respects resistance to brown streak virus resembles resistance to mosaic virus. In mosaic resistant varieties it was shown [7] that mosaic virus could frequently be traced in cuttings taken from the bases of plants which had shown no symptoms

or only transient symptoms; it was further shown that recovery frequently occurred in the second season's growth, but that *M. melanobasis* hybrids were anomalous in this respect. It is considered that resistance to mosaic virus is due in part to an ability to restrict the virus to basal parts of the plant, where it can do no harm. In view of the close parallel in the expression of resistance to the two viruses, it seems possible that resistance to brown streak is also in part due to an ability to localize the virus; that is to say, the virus may not become systemic in the stems but may be confined to the root, where, in contrast to mosaic virus, it can cause symptoms to appear.

Because of the uncertain symptom expression of plants infected with brown streak, the virus status of symptom-free stems taken from plants with diseased roots was not reliably determined. For example, in a grafting experiment with very susceptible indicator varieties, the writer obtained leaf symptoms in the indicators when severely diseased scions were used but no symptoms when symptomless shoots from diseased plants were used as scions. However, even these indicators have occasionally been recorded with brown streak symptoms present only in the root, so that a negative result in the stems and leaves does not provide unequivocal evidence of freedom from virus. The recent discovery of a technique of mechanical transmission to solanaceous indicators [6] should make it possible to determine the virus status of symptom-free plants with greater certainty.

The present observations on the effects of cool climate on the disease suggest that low temperatures may not always be the controlling factor determining symptom intensity. At Kizugu it was found that the intensity of leaf symptoms became reduced in young plants making active growth during the cool season, and at Iringa, which has a distinctly cool climate, the symptoms were frequently relatively mild in the roots and absent from the aerial parts. Thus Nichols's hypothesis to explain the absence of brown streak disease at high altitudes does not apply to this area. Confirmation of the identity of the vector seems to be necessary before an alternative hypothesis is advanced, but it may be worth noting that the disease symptoms tended to be restricted to the roots of the Iringa plants, and, if the virus itself was similarly distributed, it would not have been so accessible to an insect vector.

In general, the trials have emphasized the very considerable influence which environmental factors may have on the expression of brown streak symptoms. The effects of seasonal differences, the age of the plant, and the rate of growth taking place following infection were all very great.

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